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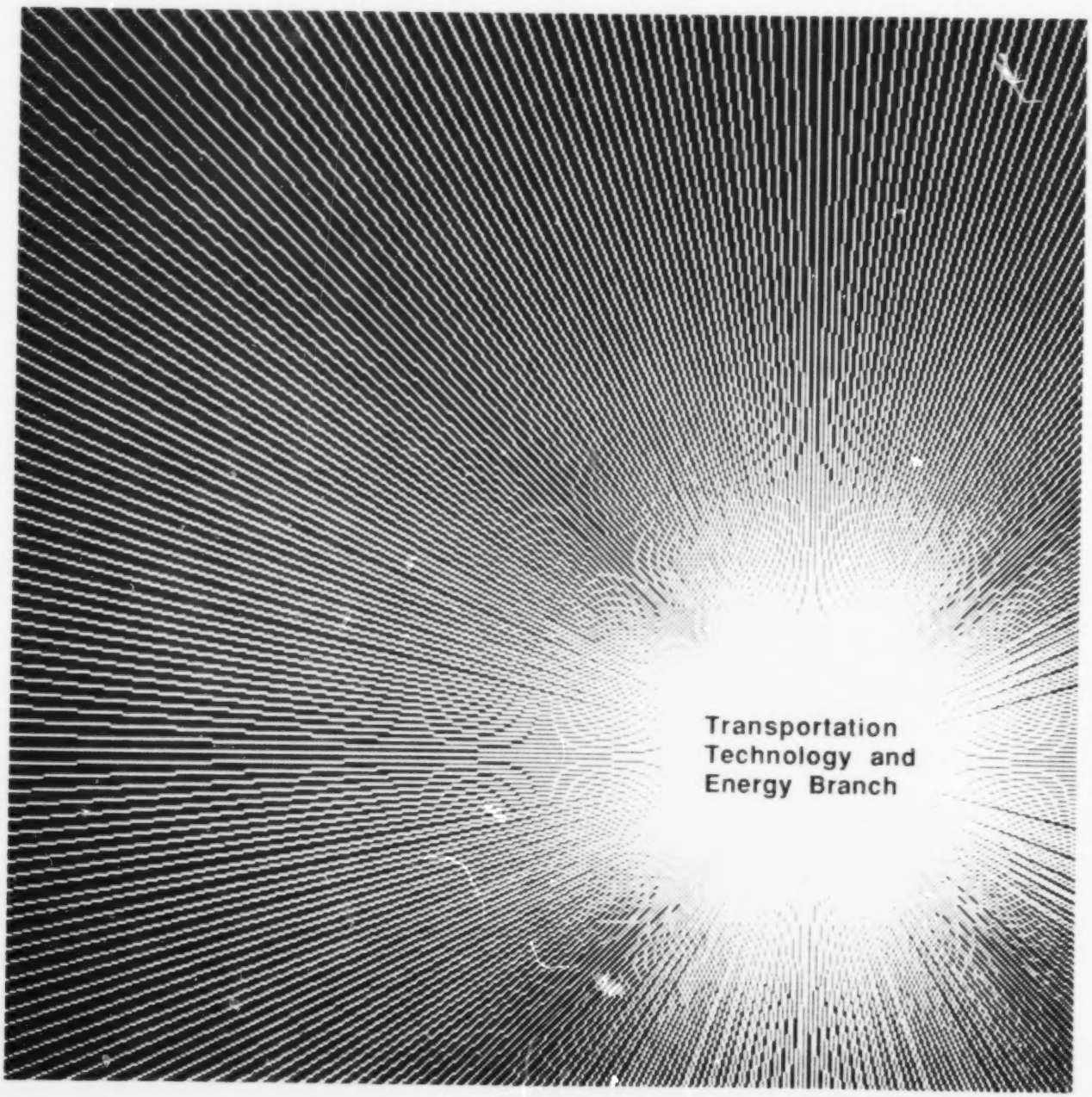

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Commuter Rail Coast Advice System – Phase I & Phase II

RATSO-90-02

Technical Report Documentation Page

Commuter Rail Coast Advice System – Phase I: Report on the Testing of a Train Driver Advice System for Fuel Conservation

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Abstract:	A fuel conservation system, consisting of software and hardware developed by the South Australian Institute of Technology for use on commuter rail trains, was tested on a four-car GO Transit commuter train. The device advises the engineperson to apply power, coast, or brake in order to operate the train in a fuel-efficient manner while maintaining the prescribed schedule. The test was conducted on a train operating in revenue service on the Lakeshore line, which is 60 km in length. The device worked effectively, resulting in fuel savings of 10% and traction energy savings of 20%.
Key words:	commuter rail, energy savings, coast advice system
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RATSO-90-02

Commuter Rail Coast Advice System

Phase I: Report on the Testing of a Train Driver Advice System for Fuel Conservation

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March 1990

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- Greg Wood, Executive Director, CIGGT
- Linda Thomas, Administrator, CIGGT
- Gordon English, co-author and collaborator, CIGGT

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*****

This report resulted from research conducted through the Canadian Institute of Guided Ground Transport. The report represents the views of the authors and does not necessarily have the endorsement of the University or the other participating organizations.

EXECUTIVE SUMMARY

A fuel conservation device (Driver Advisor System) for commuter rail trains was developed in the mid-eighties by the South Australian Institute of Technology. Tests in Australia with the prototype train-borne device yielded mean fuel savings of 15% on suburban Adelaide, Australia routes. Schedule adherence was also improved.

The Driver Advisor System uses the following energy-efficient driving strategy:

- accelerate (apply power) from the station as soon as possible using full throttle
- coast as soon as possible, but so that the train will still arrive at the next station on schedule
- brake as late as possible using full braking effort

The train operator is instructed to apply power, coast, or brake by means of a three-colour light display in the cab. The driver advisor system continually updates the algorithms in order to adapt to conditions which affect coasting performance.

During a two-week interval in 1988, the prototype driver advisor system was tested on a revenue four-car commuter train operating on GO Transit's Lakeshore line between Oakville and Pickering. Energy consumption was measured by means of a watt-hour meter connected to one traction motor. Average fuel savings of 9.7% and traction energy savings of 20.3% were realized with the device. The difference is due to the fact that the diesel engine is also providing energy for train hotel power.

FURTHER INFORMATION

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Appendix A: **ENERGY MEASUREMENTS AND TEST NOTES**

1. BACKGROUND

A project was undertaken in October 1982 by the South Australian Institute of Technology, in collaboration with the State Transport Authority of South Australia (STA) and funded by the South Australian Department of Mines and Energy and the South Australian Department of Transport.

The objectives were:

(a) to establish whether significant scope existed for energy conservation in the operation of suburban rail passenger trains;

(b) if so, to develop and demonstrate a cost-effective system to achieve that purpose.

After simulation studies and the application of optimal control theory, it was estimated that fuel savings in the range 8%-14% should be achievable on most Adelaide suburban rail services. A three-car train was equipped with fuel meters and these estimates were confirmed over two station-to-station sections in August 1983, thus achieving the first objective.

From August 1983 to March 1985, a prototype train-borne computer system was developed, installed and tested. This system provided visual advice to drivers on fuel-efficient driving tactics. The system was tested in normal service over a 35 km route with 15 stations.

The tests compared 20 runs where the drivers controlled the train normally, interspersed with 20 runs where the Driver Advice System (DAS) was used to advise the driver of optimal control of the train.

Comparative results of these two sets of runs illustrate a mean fuel saving of 15%. Timekeeping accuracy was also greatly improved, the standard deviation of arrival time being reduced from 83 seconds to less than 20 seconds.

Further tests in June 1987 showed fuel savings of almost 20% on some other Adelaide suburban routes.

Toward the end of 1987 there was collaboration between the South Australian Institute of Technology and the Canadian Institute of Guided Ground Transport, with support and exceptional cooperation from GO Transit, Canadian National Railways, and the Ontario Ministry of Transportation. This resulted in the Driver Advice System being brought to Ontario for three weeks in February 1988 for testing on GO Transit trains in normal service on the Lakeshore route. The objectives of these tests were to demonstrate the system to GO Transit, determine the magnitude of potential fuel savings in their operating environment.

2. THE DRIVER ADVICE SYSTEM

Mathematical studies have shown that for most suburban journey segments, the most energy-efficient driving strategy is:

- **accelerate** from the station as soon as possible using full throttle;
- **coast** as soon as possible, but so that the railcar will still arrive at the next stop at the correct time;
- **brake** as late as possible using full braking effort.

In practice, advice to accelerate may conflict with speed restrictions, and so the first control mode is referred to as **drive**, meaning "accelerate or cruise subject to speed restrictions."

Thus for each journey segment, the Driver Advice Unit (DAU) has to calculate the optimal times to change the driving mode from **drive** to **coast**, and from **coast** to **brake**.

The driver is given this advice in the form of an audible alert in conjunction with a tri-light display. The display is illustrated in Plates 1, 2 and 3. A green **drive** light at the left of the display is on in Plate 1 and the driver is seen to have the throttle in notch 8. A yellow **coast** light at the centre of the display is on in Plate 2 and the driver has moved the throttle to idle. A red **brake** light at the right of the display is on in Plate 3. The driver has applied the air brakes.

In order to advise the driver, the DAS unit must continuously monitor the state of the journey and calculate the feasibility of reaching the next station on time while coasting or braking.

The journey state and station arrival calculations are updated at least once every second.

The **journey state** is defined by the following parameters:

- the location of the railcar;
- the speed of the railcar;
- whether or not the railcar is coasting;
- the current time.

The location and speed of the railcar are derived from a pulse tachometer connected to one of the railcar's wheels. Each time the railcar stops at a station, the location of the railcar is checked and, if necessary, corrected. An algorithm based on the likely measurement error and driver accuracy is used to determine the correct location of the railcar.

The coasting state is detected by monitoring the throttle and brake states of the train. The driver advice system must be able to detect whether or not the railcar is coasting so that it can adapt to conditions which affect coasting performance.

The current time is determined from a battery-backed system clock.

A schematic of the hardware connections for the GO test train is shown in Figure 1.

The state of the train is monitored in relation to the route and schedule. In order to provide advice, the unit requires:

- for the train: tractive power, resistance coefficients and braking rates;
- for the route: elevation profile, speed limits, station locations and scheduled arrival times.

Plate 1

Plate 2

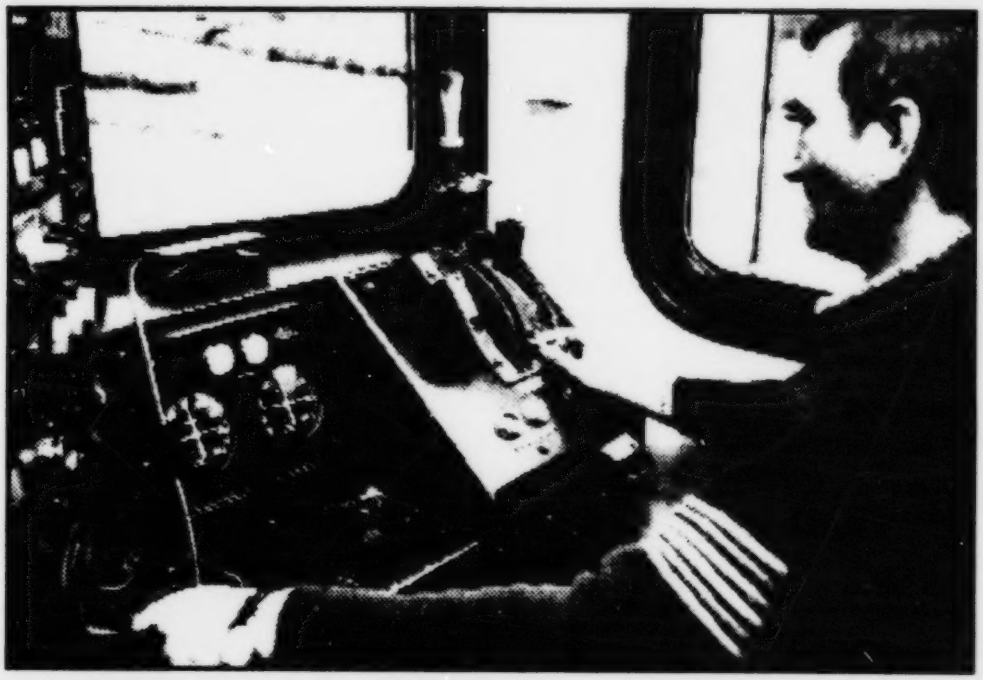
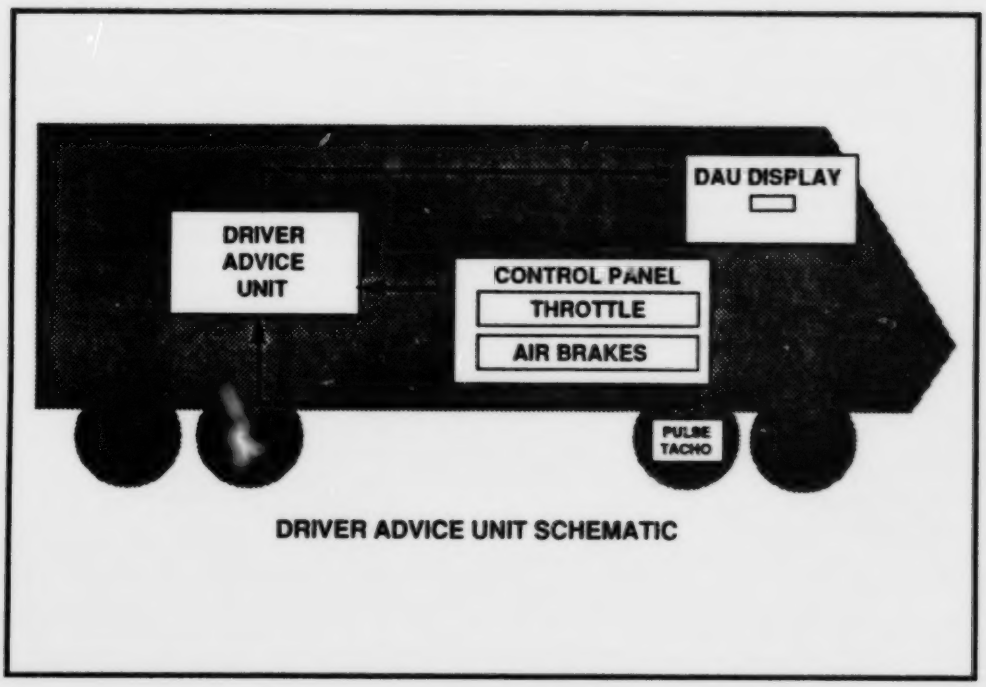


Plate 3



DRIVER ADVICE UNIT SCHEMATIC

Plate 4

3. THE DEMONSTRATION PROGRAM

The tests were done on revenue service trains in normal Lakeshore service over a two week interval in February 1988.

3.1 The Test Consist

A one-locomotive, four-coach consist with a cab control cubicle in the last coach was selected for the demonstration. This is GO's most frequently run train configuration. The locomotive was a 3000 tractive-horsepower, four-axle unit with up to 500 kW available for hotel power (General Motors Diesel Division designation F40PH). The cars were a bilevel design made by Hawker Siddeley.

Before the system arrived in Toronto, the locomotive and cab car were wired for the necessary input signals. At the same time, in Adelaide, the Driver Advice System was modified to allow the input of these signals, and to calculate fuel consumption.

For the Toronto tests, no modifications to the Driver Advice System hardware or software were required other than:

(a) addition of hardware to input the throttle control signals;

(b) addition of software to calculate fuel consumption, as described below.

3.2 The Test Route

The Lakeshore route, which is the highest density route on GO's network, was chosen for the demonstration (Figure 2). For data gathering purposes, the Lakeshore route was divided into four journeys: Toronto to Oakville, Oakville to Toronto, Toronto to Pickering, and Pickering to Toronto. Each segment is just over 33 km in length and has a schedule of 37 minutes.

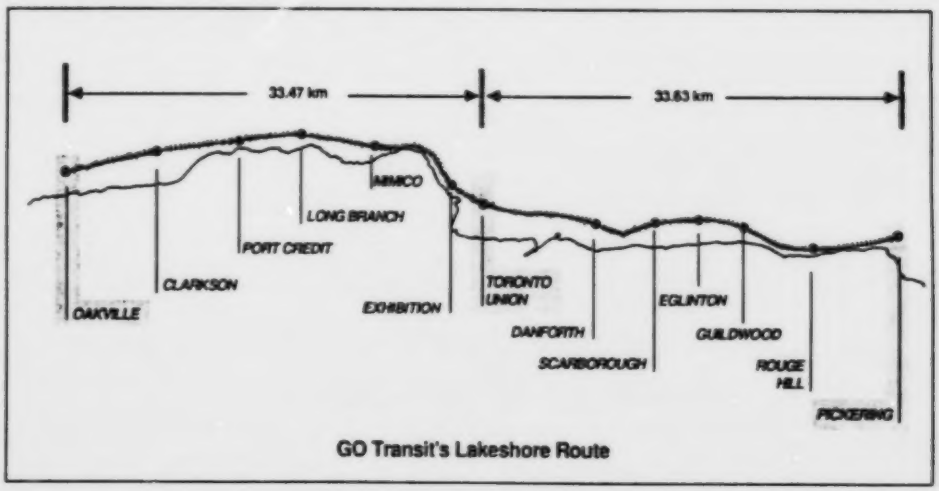


Figure 2

Figure 3 illustrates the track elevation profile and speed limits for the test route. The maximum grade in each direction between Pickering and Toronto is 1%. The locomotive governor is set to an 83 mph maximum speed.

3.3 Energy Consumption Measures

Energy consumption was measured on two sets of runs, one set without the Driver Advice System, and one set with the system.

While the previous Adelaide tests used fuel-flow meters to measure fuel consumption, two alternate measures were used in the Toronto test -- a Watt-hour meter fitted to one of the four electric traction motors and a fuel calculation based on manufacturer's specification of the fuel flow rates for each notch. The DAU continuously monitored throttle notch setting in order to perform this calculation.

There were two reasons for this choice of energy measurement. The first is the high cost and installation downtime associated with the flow meters. The second relates to the fact that the flowmeter measures consumption due to both traction and hotel power. The error introduced by variations in hotel power between tests could be significant. The two methods chosen eliminate this second problem. The traction motor energy consumption is a direct measure of traction energy and the fuel consumption calculation was based on an assumed hotel power requirement of 40 kW per coach regardless of the ambient temperature.

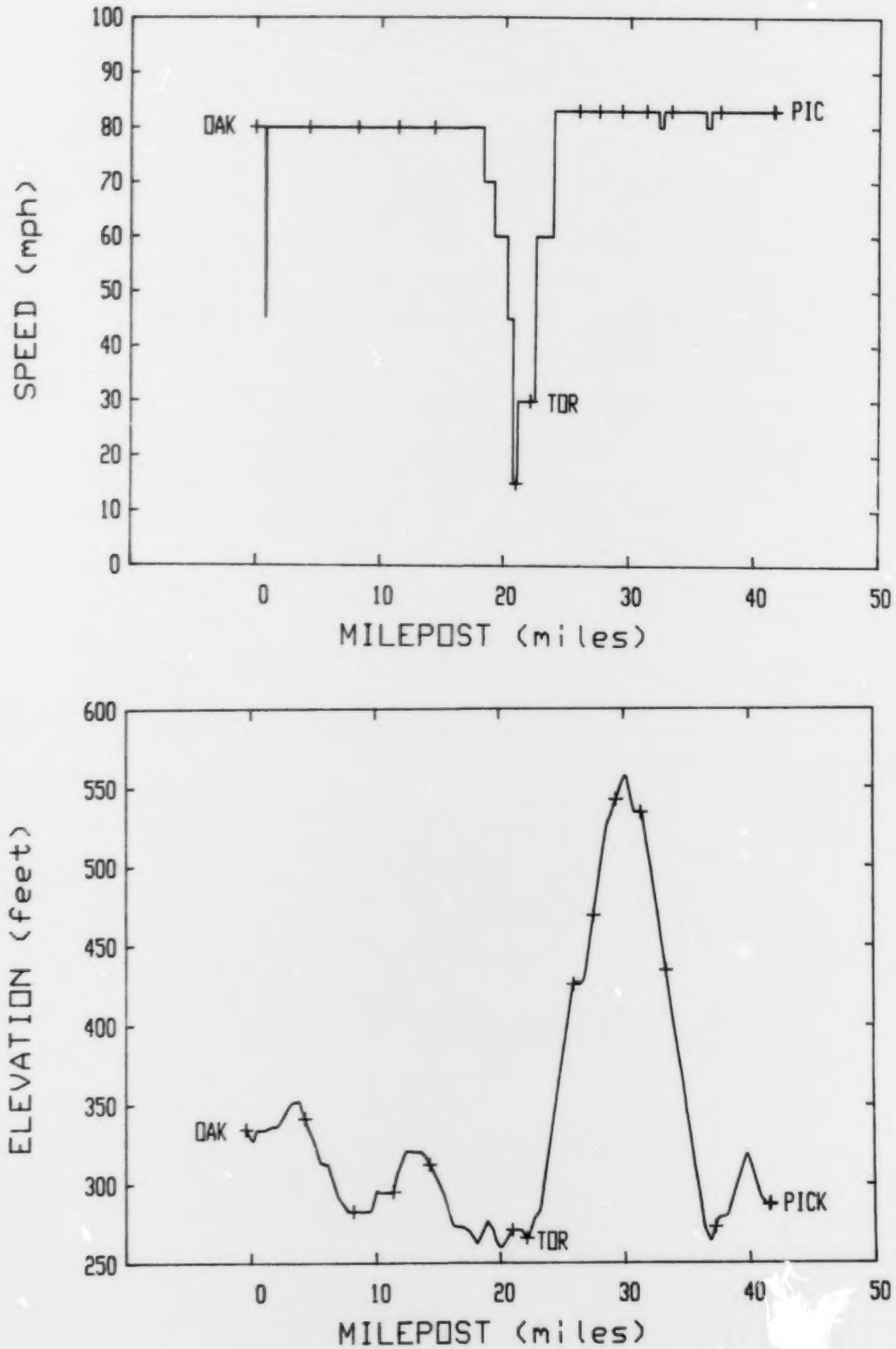

SPEED (mph)
100
90
80
70
60
50
40
30
20
10
0
OAK
PIC
TOR
0
10
20
30
40
50
MILEPOST (miles)
ELEVATION (feet)
600
550
500
450
400
350
300
250
OAK
TOR
PICK
0
10
20
30
40
50
MILEPOST (miles)

Figure 3

4. RESULTS

The intention was to collect data for at least ten runs without the system and ten runs with the system in each direction. However, the testing was hampered by the need to remove the train from service on several occasions for repairs unrelated to the fuel tests, and on two other occasions to replace a sheared lead from the wheel tachometer probe. When this happened, it usually meant that the remainder of the day's testing was lost.

Any test run, with or without advice, that was delayed near the beginning of the journey to such an extent that it was not possible to complete the journey in the scheduled time involved high fuel use while idling during the delay, and further high fuel use while attempting to make up lost time. Such high fuel use was unrelated to driving style, so such runs were irrelevant to the purpose of the test, and therefore discarded. There were three such runs.

As a result of these problems, the testing yielded a maximum of eight measurements and only five measurements on some of the route segments. The energy consumption results are presented for each route segment in Appendix A and summarized below in Figures 4, 5, 6 and 7.

For the "with-DAS" runs on the Oakville to Toronto segment (Figure b) two of the data points shown encountered operating delays which left very little room for energy minimization. For run number 1 the train left Oakville three minutes late, and then was delayed for several minutes by signals. The schedule was recovered, however, toward the end of the journey. In this case both the fuel and kWh indications were at the high level of the "without DAS" cases.

During the third run there was a 15 minute signal delay after Long Branch. However, the journey had been normal to this point, so the reading is included. The high fuel use reflects the long idling period when hotel power was being supplied. The kWh reading, on the other hand, reflects the traction energy savings between Oakville and Long Branch where the train was still on schedule.

The percentage energy savings realized with the DAU are summarized in Table 1. The "Total" reflects an average round-trip journey and yields 9.7% fuel savings and a 20.3% traction energy saving.

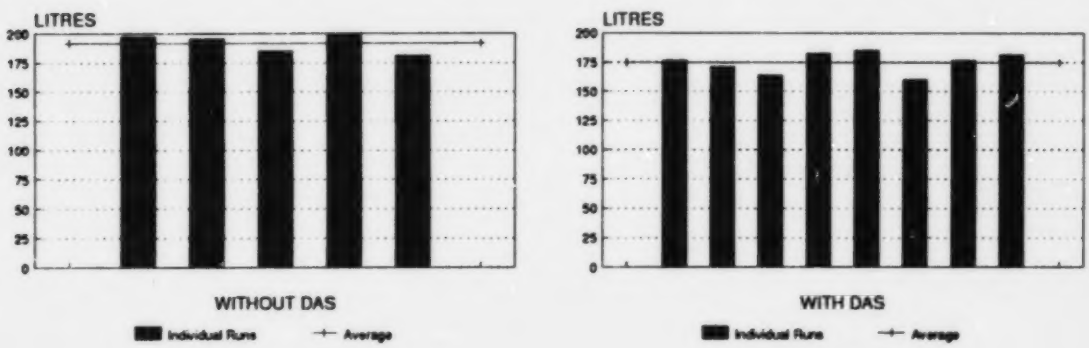
It is evident from Table 1 that the two sources of energy consumption data yield different measures of relative effectiveness. The fuel calculation includes the hotel power consumption during coasting, braking and while the train was stationary, whereas the traction motor kWh meter only records propulsion power. Thus the percentage savings from reducing the propulsive power of the train will be higher for the Watt-hour measure than for the fuel calculation.

The fuel calculation was done in litres to one decimal place. The Watt-hour meter showed accumulated Watt-hours in steps of 10 kWh. Thus, a reading of 90 kWh may correspond to any value between 90 and 100. Because of the accumulation of the measurements, low readings in one journey segment tend to result in high readings in subsequent consecutive journey segments.

ENERGY COMPARISON

TORONTO - OAKVILLE

FUEL CONSUMPTION

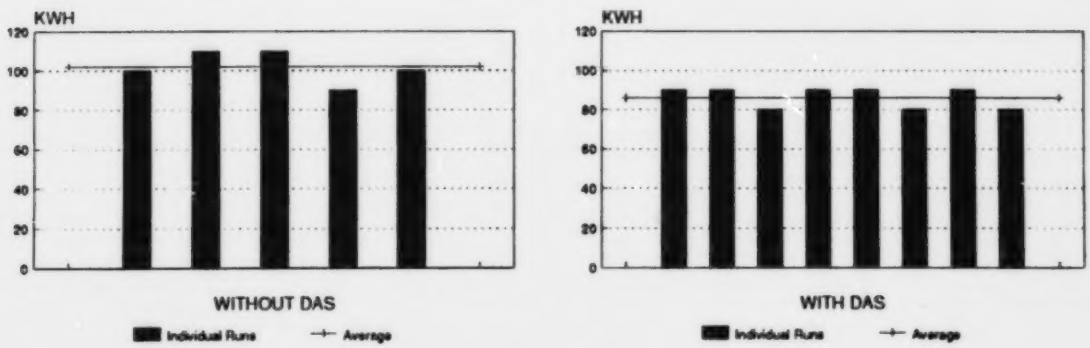


AVERAGE: 191.4

AVERAGE: 174.7

SAVINGS: 9%

TRACTION MOTOR ENERGY



AVERAGE: 102

AVERAGE: 86

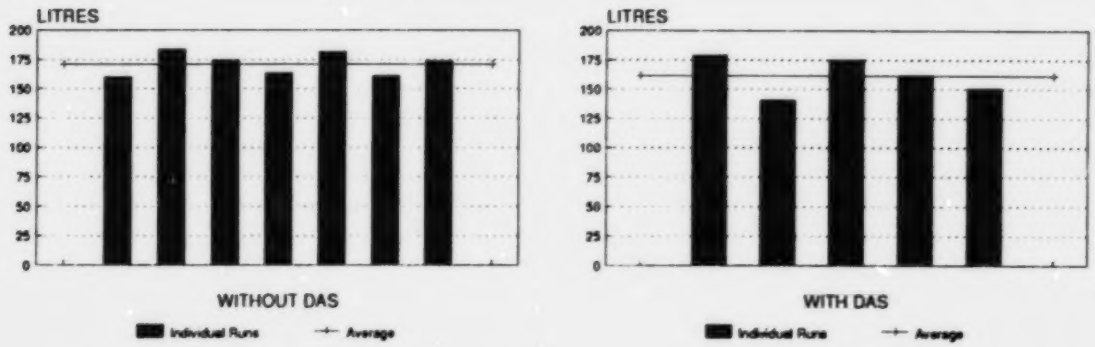
SAVINGS: 16%

Figure 4

ENERGY COMPARISON

OAKVILLE - TORONTO

FUEL CONSUMPTION

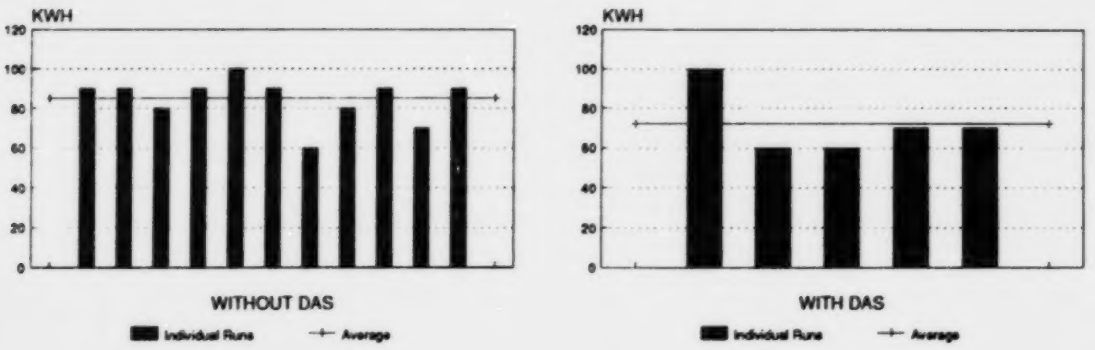


AVERAGE: 171.0

AVERAGE: 161.5

SAVINGS: 6%

TRACTION MOTOR ENERGY



AVERAGE: 85

AVERAGE: 72

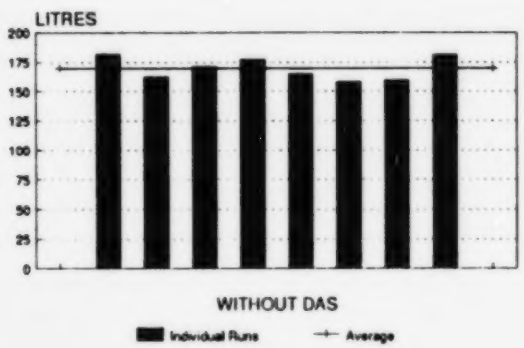
SAVINGS: 15%

Figure 5

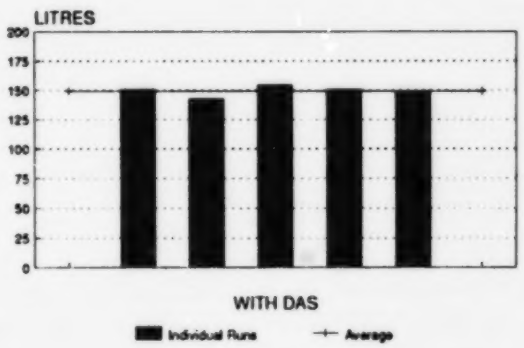
ENERGY COMPARISON

TORONTO - PICKERING

FUEL CONSUMPTION



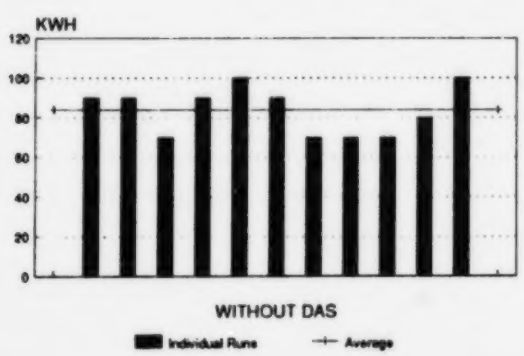
AVERAGE: 169.6



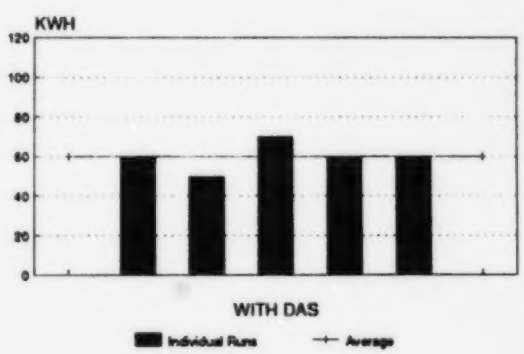
AVERAGE: 149.3

SAVINGS: 12%

TRACTION MOTOR ENERGY



AVERAGE: 84



AVERAGE: 60

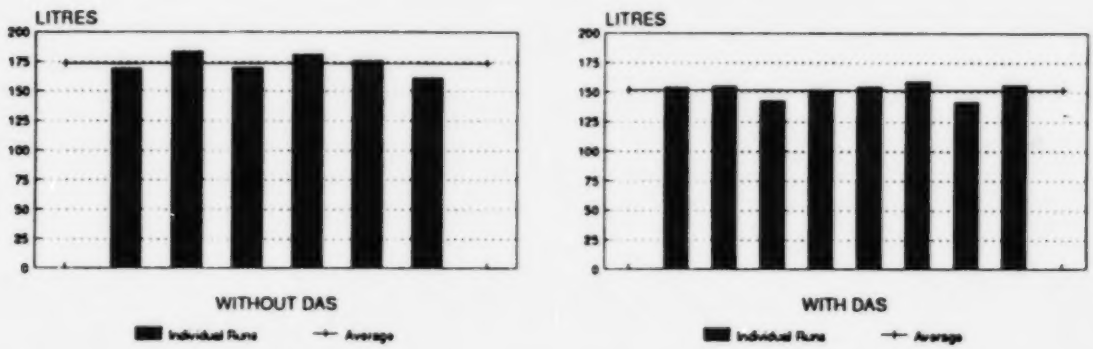
SAVINGS: 29%

Figure 6

ENERGY COMPARISON

PICKERING - TORONTO

FUEL CONSUMPTION

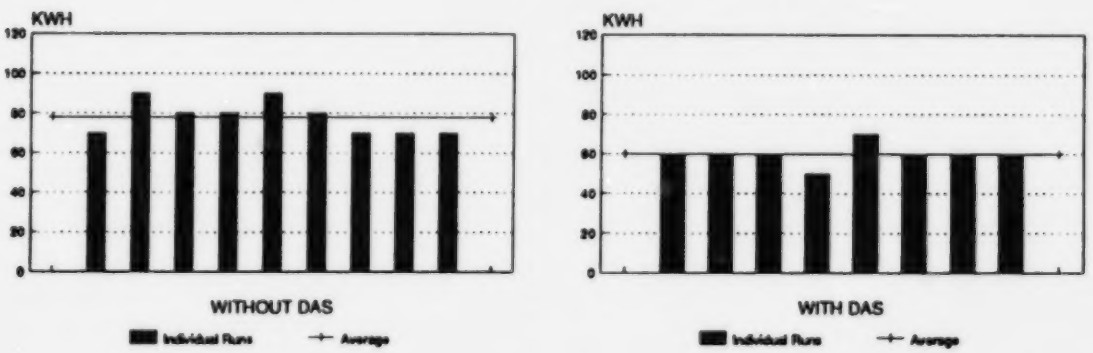


AVERAGE: 173.4

AVERAGE: 151.6

SAVINGS: 13%

TRACTION MOTOR ENERGY



AVERAGE: 78

AVERAGE: 60

SAVINGS: 23%

Figure 7

Table 1

Energy Savings with the Driver Advice Unit

Route Segment	Average Fuel Consumption [litres] With DAS	Without DAS	% Saved	Average Traction Energy [kWh] With DAS	Without DAS	% Saved
Toronto-Oakville	174.7	191.4	8.7	86	102	15.7
Oakville-Toronto	161.5	171.0	5.6	72	85	15.3
Toronto-Pickering	149.3	169.6	12.0	60	84	28.6
Pickering-Toronto	151.6	173.4	12.6	60	78	23.0
Total	637.1	705.4	9.7	278	349	20.3

The maximum effect of the low resolution of the kWh meter would be to reduce the 20.3% savings to 17.5%. This is under the unrealistic assumption that all of the "with-DAS" readings were low by 10 kW while all the "without-DAS" readings were accurate.

The Oakville to Toronto segment has the lowest savings indication at only 5.6%. This is due to the fact that two of the five runs had operational delays as discussed above. With these two data points discarded, the average savings for that segment become 11.6%, which is consistent with the results for other segments. The total round trip savings on this basis would be 11%.

The other low reading is the Toronto to Oakville segment. A crew change is made at Mimico on almost all trips at this point for either lunch break or shift end. This results in a schedule catch up situation for the major portion of the trip. However, this is the normal operating practice. Unless the crew change point were moved to Oakville, Toronto or Pickering, the savings potential will always be lower on this segment of the route. If the crew change point were changed, one would expect to realize savings of the same magnitude as the rest of the route (i.e. 11 to 12%).

5. CONCLUSIONS

It is concluded from this review of the data that a savings potential in the order of 11% exists for the four-car consists operating on the Lakeshore route. This consist-service combination is the dominant one for GO operations. However, there are other consists and other routes. The Lakeshore route has ten-car consists during peak periods. These trains use the same locomotive as the four-car consists and thus have much less slack in the schedule (and probably less potential for fuel savings). There is no reason to expect the percentage fuel savings on the other routes to be any less than measured in the tests.

APPENDIX A

ENERGY MEASUREMENTS AND TEST NOTES

Toronto to Oakville (See Note 1)

Without Advice System		With Advice System		
Fuel	kWh	Fuel	kWh	
-	100	176.8	90	(see Note 2)
197.0	110	171.3	90	
195.3	110	163.9	80	
185.1	90	182.5	90	
198.5	100	185.1	90	
181.2	-	160.0	80	(see Note 3)
		176.7	90	
		181.5	80	
Mean 191.4	102	Mean 174.7	86	
Fuel Saving: 9%		kWh saving: 15%		

1. All runs except one involved a crew change and brake check at Mimico. This caused a delay at the station, resulting in the train being behind schedule at every station until either the second to last station, or occasionally the end of the journey. Little or no coasting was possible, so fuel use with and without the system was abnormally high.

2. During some of the early runs without advice, trouble with the tachometer signal resulted in the train interface being dismantled in an effort to trace the problem (later found elsewhere). Thus calculation of fuel use was not possible. In such cases, the Watt-hour reading was still recorded.

3. For the run without advice, the Watt-hour reading was overlooked.

Oakville to Toronto (see Note 4)

Without Advice System		With Advice System		
Fuel	kWh	Fuel	kWh	
-	90	179.2	100	(see Note 5)
-	90	140.9	60	
160.0	80	175.2	60	(see Note 6)
-	90	162.1	70	
183.8	100	150.3	70	
174.0	90			
163.5	60			
-	80			
181.7	90			
160.8	70			
173.9	90			
Mean 171.0	85	Mean 161.5	72	
Fuel saving: 6%		kWh saving: 15%		

4. On the first day of testing with the Driver Advice System it was found that the wheel tachometer at the locomotive end had its lead sheared off, so all eastbound runs were without advice, but fuel use was available. The following day the train was out of service for the lead to be repaired. On two subsequent days, delays to eastbound runs were so great that the train was substantially behind schedule for the whole journey. In such cases the results were irrelevant to the tests.

5. For this run with advice, the train left Oakville three minutes late, and then was delayed for several minutes by signals. The train, however, achieved some coasting toward the end of the journey.

6. During this run with advice, there was a 15 minute signal delay after Long Branch. However, the journey had been normal to this point, so the reading is included. The high fuel use is partly due to idling for such a long time, and partly due to an attempt to make up lost time.

Toronto to Pickering

Without Advice System		With Advice System	
Fuel	kWh	Fuel	kWh
-	90	150.4	60
181.7	90	142.6	50
162.5	70	154.3	70
171.4	90	150.7	60
-	100	148.7	60
177.1	90		
165.0	70		
-	70		
158.2	70		
159.2	80		
181.3	100	____	__
Mean 169.6	84	Mean 149.3	60

Fuel saving: 12% kWh saving: 29%

Pickering to Toronto

Without Advice System		With Advice System	
Fuel	kWh	Fuel	kWh
169.5	70	154.0	60
183.5	90	154.8	60
169.6	80	142.8	60
-	80	150.2	50
181.2	90	154.4	70
175.7	80	158.8	60
-	70	141.4	60
-	70	156.1	60
161.0	70	____	__
mean 173.4	78	Mean 151.6	60

Fuel saving: 13% kWh saving: 23%

Commuter Rail Coast Advice System – Phase II

RATSO-90-02

Technical Report Documentation Page

Commuter Rail Coast Advice System – Phase II: Reassessment of the Economics of a Coast Advice System for GO Transit

Prepared by:	**The Canadian Institute of Guided Ground Transport**
Authors:	**G.W. English, T.W. Moynihan, H. Boumeester**
Prepared for:	Rail and Advanced Transportation Systems Office Transportation Technology and Energy Branch Ministry of Transportation J. Young, Project Manager
Report No.:	RATSO-90-02
Date:	March 1990
Published by:	Rail and Advanced Transportation Systems Office Transportation Technology and Energy Branch Ministry of Transportation
Abstract:	Fuel savings obtained from the original tests of the Driver Advisor System on GO Transit commuter rail trains were used in conjunction with event recorder data to simulate the anticipated fuel savings to be obtained from installing the device on the new GO Transit standard locomotive, the GMD F59PM. Simulation results indicated that trains using the F59PM locomotives on GO Transit commuter rail lines would be very similar to those obtained in the original field tests of the device. Economic assessments based on the fuel savings are calculated based on a fleet-wide installation of the device on GO Transit Commuter Rail Operations.
Key words:	commuter rail, energy savings, coast advice system, economic assessment
Distribution:	by request
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RATSO-90-02

Commuter Rail Coast Advice System

Phase II: Reassessment of the Economics of a Coast Advice System for GO Transit

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Appendix A: EVENT RECORDER SUMMARY TABLES

Appendix B: SUITABILITY OF EXISTING CIGGT CONTROLLERS

EXECUTIVE SUMMARY

A prototype train-borne computer system (Driver Advisor) designed to advise train operators on fuel-efficient driving tactics was tested on GO Transit's Lakeshore commuter line in 1988. Since the completion of the original tests, GO Transit began a program to re-equip its locomotive fleet with state-of-the-art F59PH locomotives. These locomotives have higher acceleration and braking rates as well as improved overall efficiency. These changes in locomotive performance and efficiency raised questions concerning the economic impact of a coast advice system.

Using the results of the original 1988 tests and event recorder data from F59PH locomotives in revenue service, a validated computer model of a driver-advisor equipped F59PH locomotive was developed. Fuel savings in the 20% range were predicted for F59PH's equipped with a coast advice system operating on GO Transit's Lakeshore line, even with the locomotive's inherent efficiency improvements. It is estimated that these fuel savings would result in annual fuel savings of $280,000 if the device was installed fleet wide.

An examination was also made concerning the use of the CIGGT long-train control algorithms as a basis for a coast advice system. A brief analysis indicated that it is entirely feasible to adapt the CIGGT algorithms to this need.

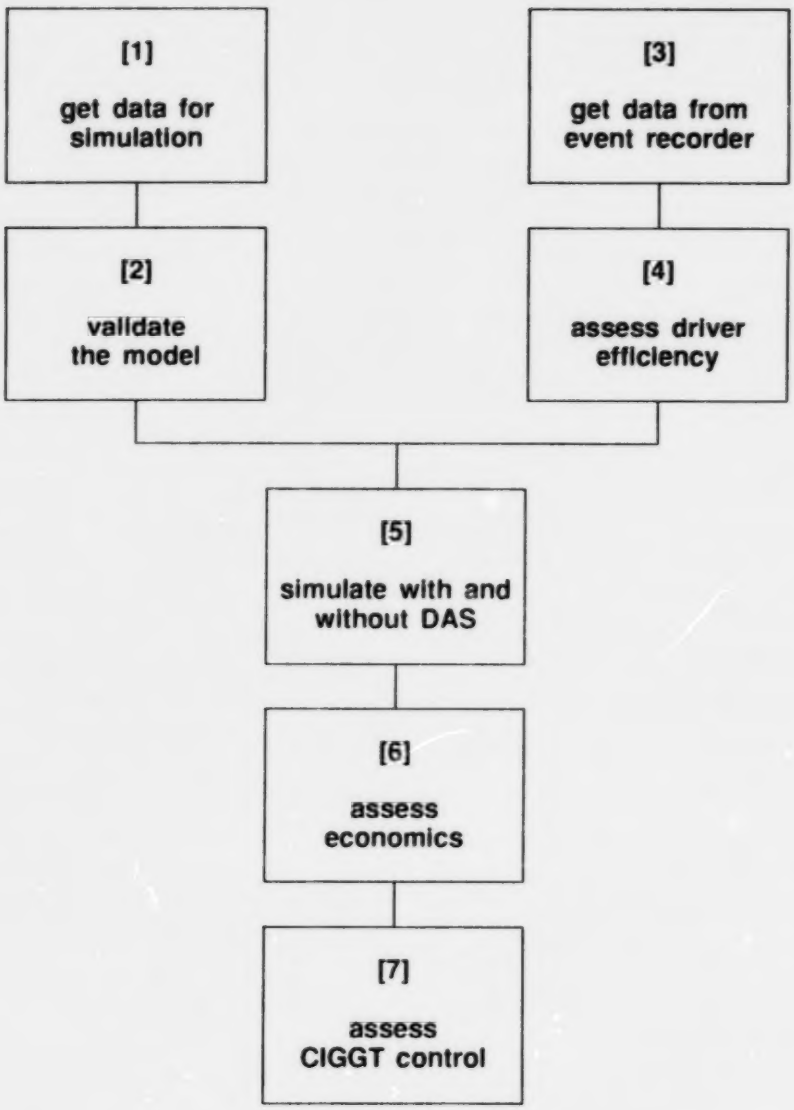


Figure 1 Principal tasks undertaken

1. INTRODUCTION

A team of Australian researchers have developed a prototype train-borne computer system which provides visual advice to drivers on fuel efficient driving tactics. The system was tested in Australian service and demonstrated a mean fuel saving of 15%. Timekeeping accuracy was also greatly improved; the standard deviation of arrival time being reduced from 83 seconds to less than 20 seconds.

One of the Australian researchers visited Canada to discuss previous CIGGT research in automatic control of long freight trains. Through collaboration between the South Australian Institute of Technology and the Canadian Institute of Guided Ground Transport, with support and cooperation from GO Transit, Canadian National Railways, and the Ontario Ministry of Transportation, the Driver Advice System was brought to Ontario for three weeks in February 1988 for testing on GO Transit trains. Tests were undertaken on revenue service trains in normal service on GO Transit's Lakeshore route.

A one-locomotive, four-coach consist with a cab control cubicle in the last coach was selected for the demonstration. This was GO's most frequently run train configuration. The locomotive was a 3000 tractive-horsepower, four-axle unit with up to 500 kW available for hotel power (GMD F40PH). The cars were a bi-level design made by Hawker Siddeley.

Fuel savings of 6% to 13% were realized in the tests and it was concluded that a savings potential in the order of 11% exists for the four-car consists operating on the Lakeshore route.

This consist-service combination is the dominant one for GO operations. However, there are other consists and other routes. The Lakeshore route has ten-car consists during peak periods. These trains use the same locomotive as the four-car consists and thus have less slack in the schedule (and therefore less potential for fuel savings).

Since the tests were undertaken, GO Transit renewed its locomotive fleet with state-of-the-art F59PH locomotives. These locomotives have a much higher acceleration and braking performance as well as improved efficiency. GO personnel have estimated the fuel savings from these locomotives to be 22%. They have also eliminated one locomotive from their 10-coach consist. In addition, the Lakeshore route has been extended on its east end from Pickering to Whitby with subsequent schedule and consist modifications.

These changes in operations and in locomotive efficiency and performance raised questions about the impact on the economics of the DAS. The objective of this investigation was to reassess, via computer simulation, the economics of DAS with the new equipment and the extended Lakeshore route.

From the outset of the testing there has been an objective of creating a Canadian role in this area. A second objective was to assess the suitability of the controllers developed at CIGGT (for full automatic control of long freight trains) to the advisory role of commuter trains.

The principal tasks involved in undertaking this assessment are illustrated in Figure 1 (opposite).

2. DATA COLLECTION

2.1 Route Data

The required route data includes both profile and schedule information. The vertical profile for the Lakeshore route with station locations shown is illustrated in Figure 2.

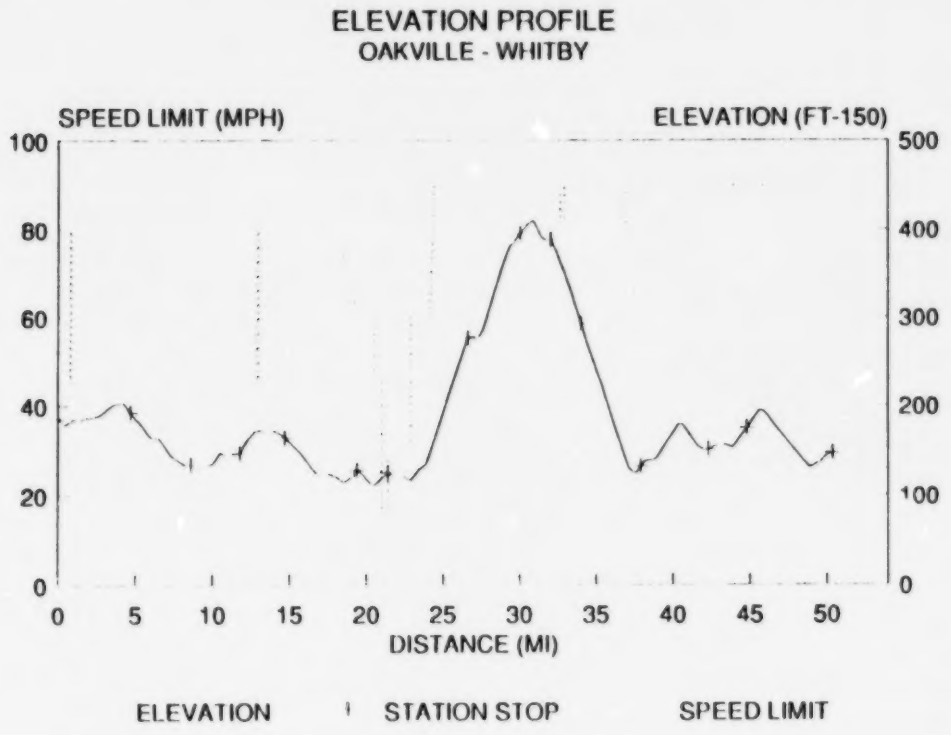


Figure 2

Tractive Performance
F59PH Locomotive

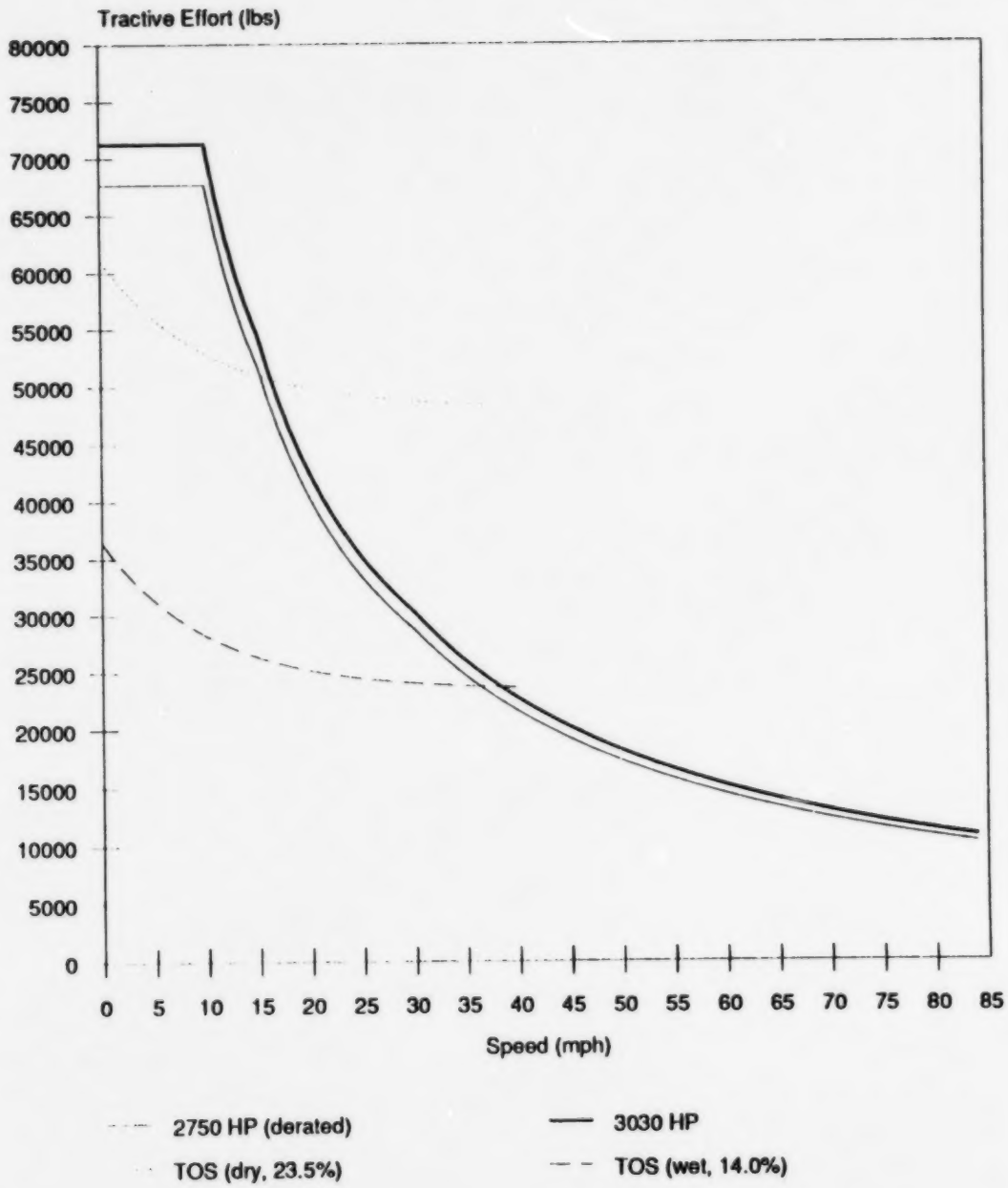


Figure 3

2. DATA COLLECTION

2.1 Route Data

The required route data includes both profile and schedule information. The vertical profile for the Lakeshore route with station locations shown is illustrated in Figure 2.

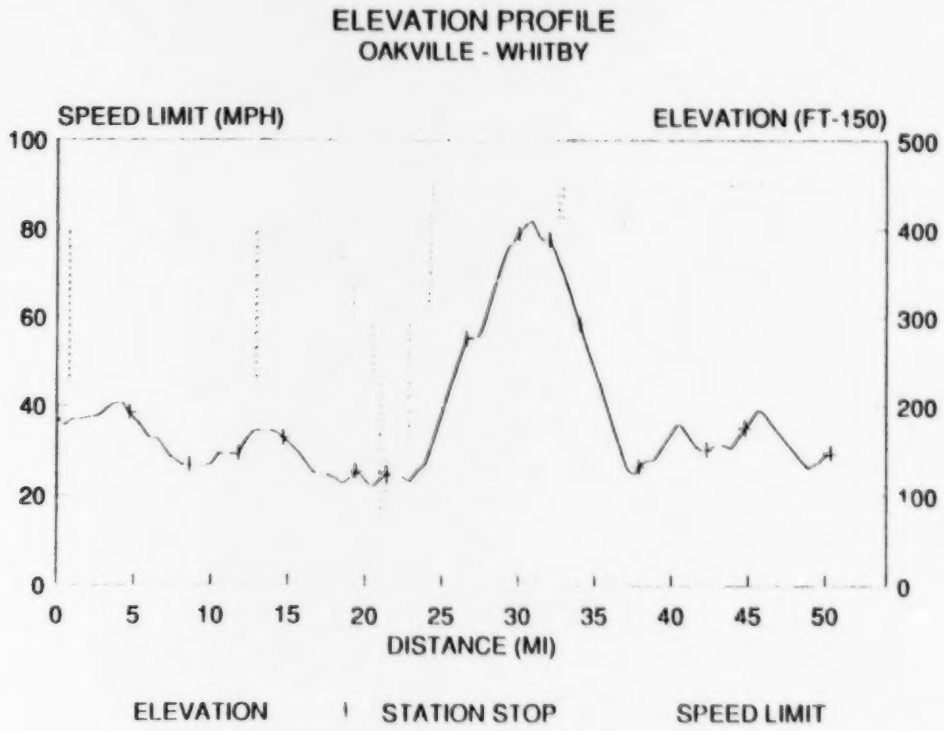


Figure 2

Tractive Performance
F59PH Locomotive

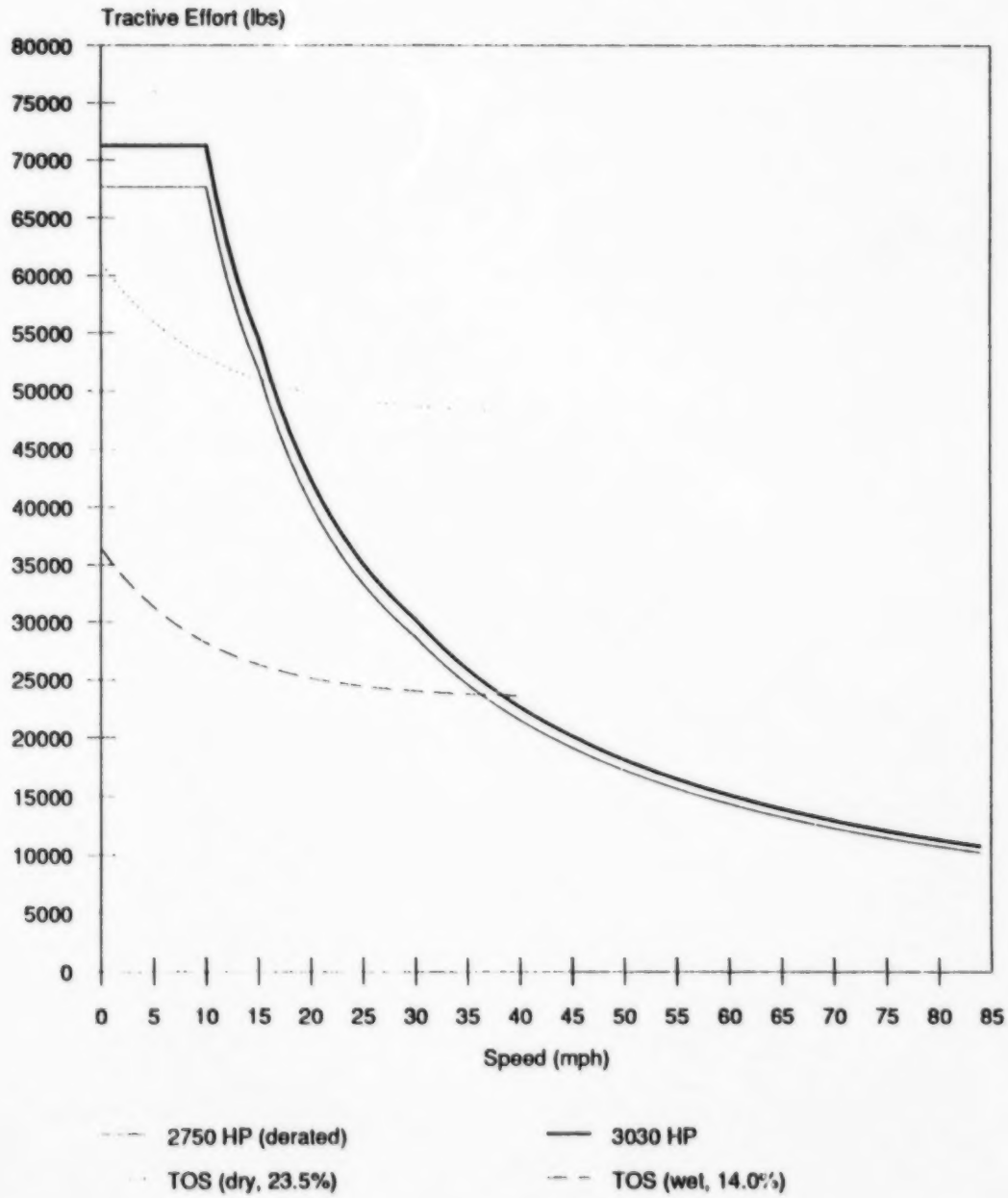


Figure 3

2.2 Train Data

The data obtained for the F59 locomotive included fuel consumption rates (Table 1) and tractive effort curves (Figure 3, opposite).

The train resistance coefficients and other characteristics pertinent to the simulation of GO train operations are presented in Table 2.

Table 1: Locomotive Data

	F59			F40
Throttle Notch	RPM	HP	Fuel Cons. (l/hr)	Fuel Cons. (l/hr)
8 (full)	904	3030	553.7	642.9
8 (derated)	852	2750	496.9	-
7	820	2575	461.4	580.2
6	729	1725	309.1	459.7
5	651	1360	257.3	363.0
4	568	995	187.3	289.4
3	490	725	138.2	238.6
2	343	340	71.4	195.1
1	269	191	44.1	161.8
Idle (normal)	270	0	11.8	121.9
Idle (low)	200	0	7.7	-
DB1	269	0	11.8	-
DB3	490	0	21.4	-

Table 2: Train Resistance Coefficients and Characteristics

	F59PH	Bi-Level
Length	58.2'	85.0'
Weight	130 tons	54 tons (tare)
Rotational Inertia	9 tons	3 tons
Ro	72	72
Rw	1.5	1.5
Rvw	0.03	0.03
Rv2	0.24	0.045

2.3 Event Recorder Data

Event recorder data were obtained for a range of train runs. These data were used to validate the simulation model and to derive energy efficiency and timekeeping performance estimates for the existing non-DAS operation.

A computer program was written to extract the desired information from the recorded data and to calculate dependant information of interest (e.g., train location and fuel consumption).

Figure 4 illustrates the nature of data extracted. In it, the speed, throttle setting and air brake pressure for a GO #952 from Oakville to Union station are plotted against time. Fuel consumption was calculated from time spent in each throttle setting and the manufacturer's fuel consumption data. For the illustrated train run, the total fuel consumption was 129 litres.

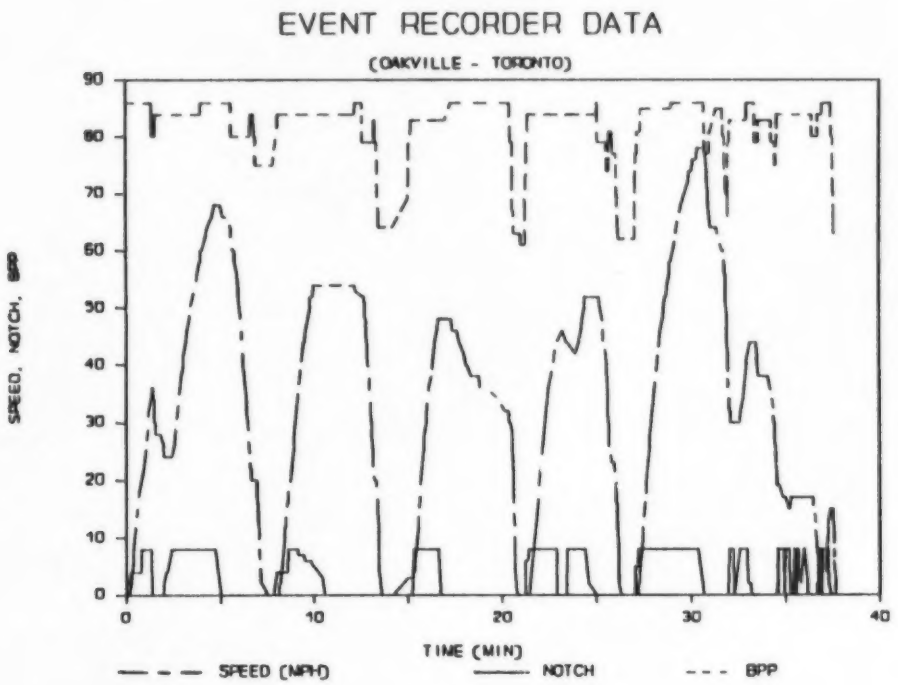
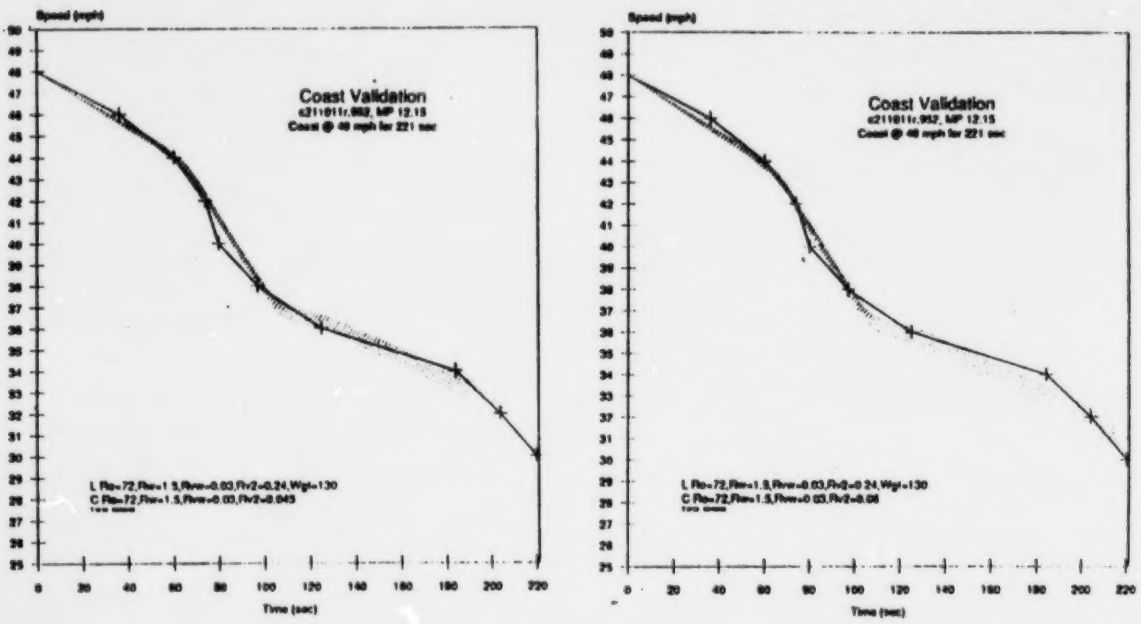
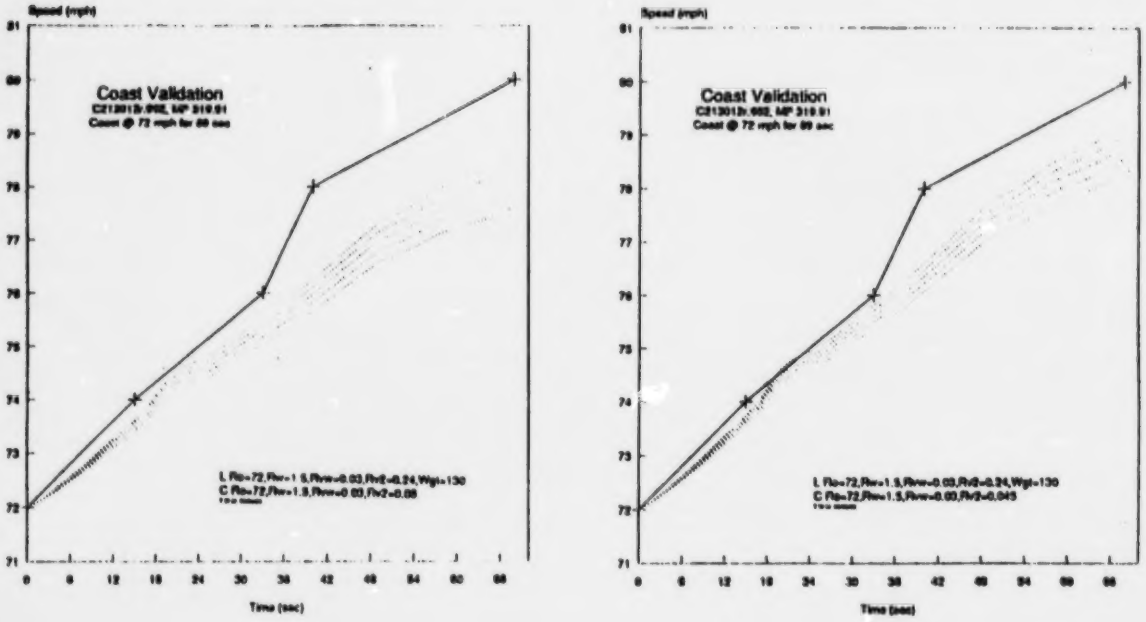


Figure 4



(a) (b)

Figure 5



(a) (b)

Figure 6

3. MODEL VALIDATION

There were two areas of validation -- the train data to be used in the simulation and the simulation model itself. The event recorder speed data was the main source of validation; although its accuracy was limited by a 2 mph resolution in recorded data.

3.1 Train Characteristics

To validate the train characteristics used in the simulation model, several representative segments were extracted from the event recorder data and compared with time-velocity data generated using the Train Operation Simulator (TOS) Release 3. Two coasting segments, one at low speed and the other at high speed, were used to investigate the train resistance coefficients and assess the model's mass sensitivity. Three driving segments, at constant throttle notch 8, were then examined to verify the locomotive's tractive effort and adhesion.

The values selected for rotational inertia and the Davis Equation coefficients Ro, Rw and Rvw, as listed in Table 1, represent generally accepted values for the type of vehicles in use. The drag coefficient, Rv2, for the F59PH locomotive is also a generally accepted value, while that for the bi-level cars was considered less established and required some refinement. Figures 5 and 6 (opposite) compare recorded velocity-time history (solid curve) with corresponding data generated by TOS (dotted curves) for a range of bi-level car weights from 54 ton (empty, lowest dotted curve) to 70 ton (full, highest dotted curve) in 4 ton passenger load increments.

Figure 5(a) depicts a low-speed coast between the Port Credit and Long Branch stations with bi-level drag coefficient of 0.06, while Figure 5(b) shows improved correlation when this drag coefficient is reduced to 0.045. After approximately 180 seconds of event record data, the consist enters a curve on level grade and begins to decelerate rapidly. This trend is not observed in the simulated runs as curving losses were not included.

Figure 6(a) depicts a high-speed coast along a -1% to -1.5% downgrade between Guildwood and Rouge Hill stations with bi-level drag coefficient of 0.06. Reducing the bi-level car's coefficient of drag to 0.045 at this high speed significantly improves the fit between recorded and simulated data, as illustrated in Figure 6(b). The cause of divergence demonstrated between 32 and 38 seconds is considered related to inaccuracies in the velocity record or track profile data. It was felt that further reduction of the bi-level car drag coefficient to reduce this divergence would result in an artificially low coefficient of drag.

The F59PH locomotive throttle notch 8 tractive performance curves, previously given in Figure 3, include two curves which illustrate the limits which TOS places on tractive effort produced on dry rails where an adhesion of 23.5% at 0 mph (dotted curve) is assumed and on wet rails where the adhesion is reduced to 14.0% at 0 mph (dashed curve). Figure 7 (over) shows excellent correlation between event record data (solid curve) and TOS simulated data (dotted curve) in the horsepower limited region of the derated F59PH's tractive effort capability. However, at lower speeds where tractive effort is limited by the wheel-rail adhesion, the actual tractive effort produced is somewhat lower than that predicted by the simulation model. Figure 8(a) (over) demonstrates one instance where at low speed the actual tractive effort produced (solid curve) falls between that predicted by TOS for dry rails (dotted curve) and for wet rails (dashed curve). In another example, illustrated in Figure 8(b) (over), the actual tractive effort (solid curve) is very close to that predicted by TOS assuming wet rails (dashed curve).

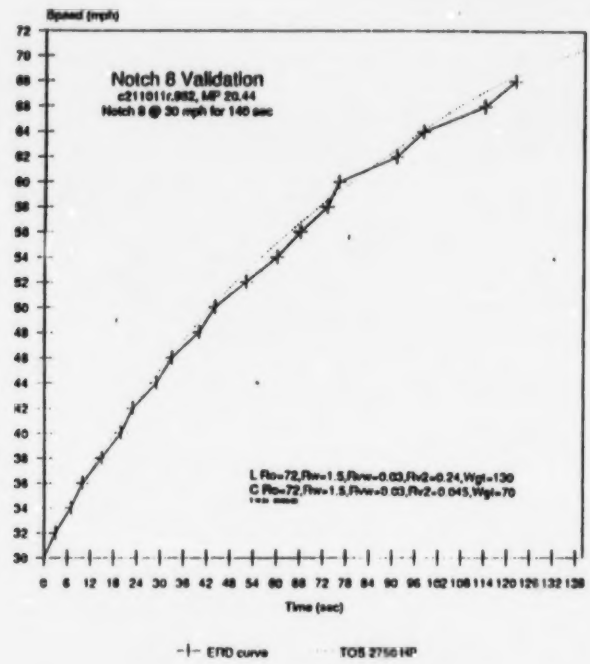


Figure 7

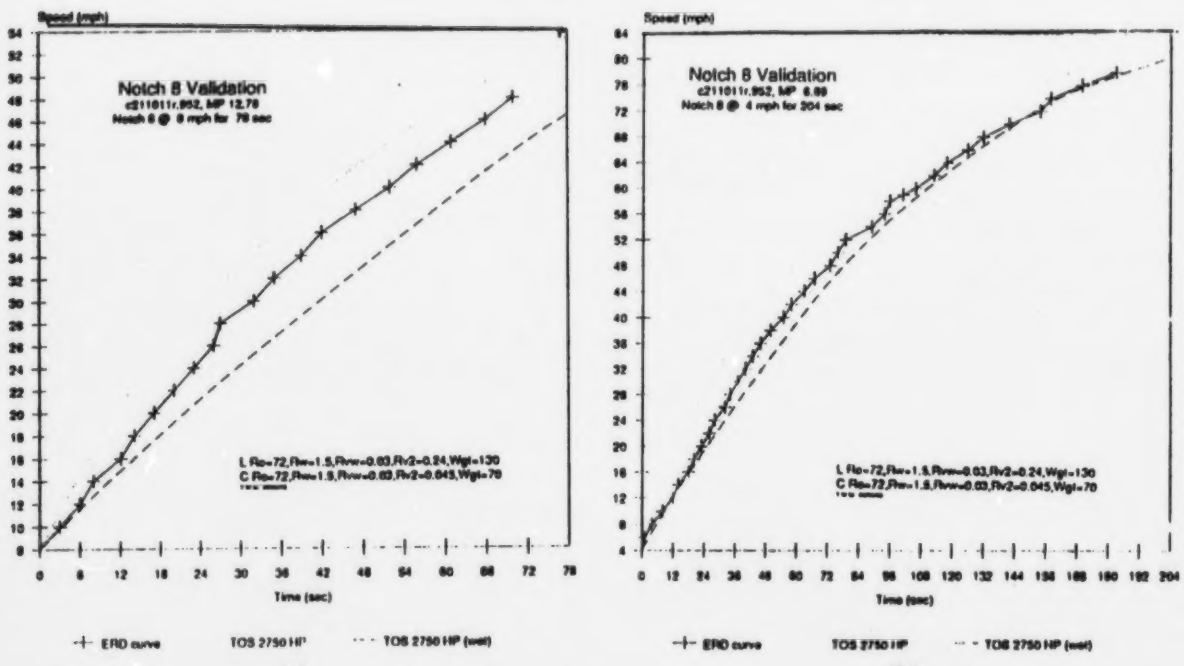


Figure 8

Another element of the validation was the fuel savings obtained in the 1988 tests. The files retrieved from the event recorders were used to compare the savings measured in actual field tests with the predictions of the current simulation study. This was possible because the F59 locomotives are at present operating at a reduced power awaiting turbocharger modifications. The derated power of the F59 is very close to the full power of the F40 locomotives with 5-car hotel power extracted.

3.2 Model Predictions

The actual train handling of the drivers was monitored to derive fuel consumption with the F59 fuel consumption specifications and then with the F40 fuel consumption rates used in the original DAS tests. As described in more detail in the following sections, the same train runs were monitored with a coast advisor interface and the fuel consumption with coasting was assessed.

The results provide two levels of validation:

(a) F59 fuel savings over the F40 in GO's operating environment;
(b) DAS fuel savings under conditions similar to the original test environment.

3.2.1 F59 Locomotive Savings Compared to the F40

As Table 3 illustrates, the simulation-based fuel savings of the F59 locomotives exceed the predicted levels of 22%. However, the F59 supplies hotel power from a separate diesel-generator whereas the F40 supplies it from the main diesel engine. With the energy consumed by the separate diesel engine in the F59 added in, the savings are in the 20% - 30% range.

Table 3: Fuel Consumption Comparison

		Data Set			
Segment	Locomotive	A	B	C	D
Oakville-Toronto	F40	206	203	205	178
	F59	129	129	129	104
Toronto-Whitby	F40	280	262	270	267
	F59	177	164	172	170
Whitby-Toronto	F40	340	289	282	313
	F59	207	184	177	203
Toronto-Oakville	F40	176	212	171	232
	F59	106	137	100	154
Average for Round Trip	F40		971.42		
	F59		610.45		

3.2.2 Coast Savings Compared With The Original Tests

The savings expected from a coast advisory under normal driving conditions with the F40 locomotive's characteristics are summarized in Table 4. While the range is wider than the test results of 1988, the average of 13% compares very well with the 9% to 14% range obtained in the original tests.

Table 4: Potential Fuel Savings from Coast Device

	F40 Locomotive				F59 Locomotive			
	Consumption		Savings		Consumption		Savings	
Segment	Driver (litres)	Advice (litres)	Litres	%	Driver (litres)	Advice (litres)	Litres	%
Oakville-Toronto	206	155	51.6	25	129	82	46.9	36
	203	149	53.9	27	129	79	49.9	39
	205	159	45.7	22	129	87	41.8	33
	178	156	22.1	12	104	84	19.6	19
Toronto-Whitby	280	264	16.4	6	177	161	16.2	9
	262	237	25.0	10	164	137	27.6	17
	270	227	42.3	16	172	128	44.0	26
	267	228	39.5	15	170	128	41.2	24
Whitby-Toronto	340	340	0.0	0	207	207	0.0	0
	289	249	40.7	14	184	143	41.5	23
	282	246	35.7	13	177	140	36.4	21
	313	270	43.4	14	203	160	42.9	21
Toronto-Oakville	176	159	16.7	9	106	87	19.0	18
	212	155	56.4	27	137	82	54.8	40
	171	158	12.4	7	100	88	12.3	12
	232	216	15.8	7	154	138	16.4	11
Total	3885	3368	517.5		2441	1931	510.4	
Average Saved			32.34	13			31.90	21

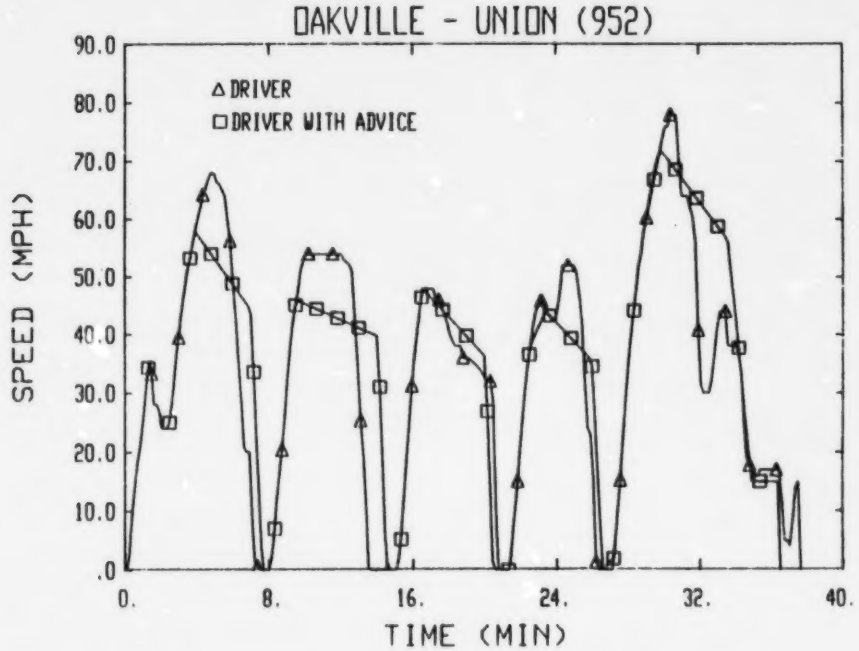


Figure 9 Event recorder data with coast advice superimposed

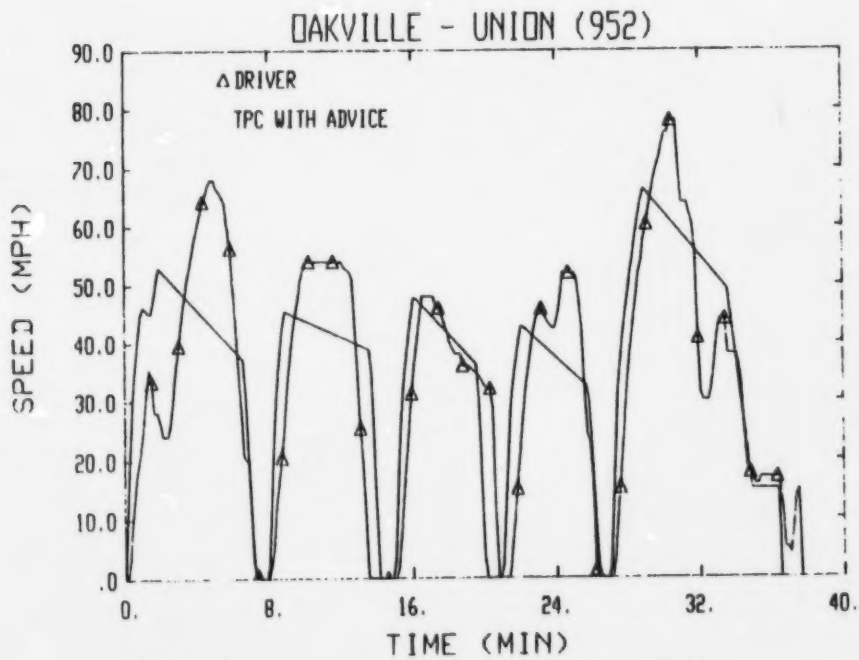


Figure 10 Simulated train run with coast advice

4. FUEL SAVINGS PREDICTIONS FOR DAS WITH THE F59 LOCOMOTIVE

The same data assessed above for validation reasons were used in an analysis of the savings potential of a coast advisory system with existing train handling practices and a derated F59 locomotive. The results are summarized in Appendix A. As illustrated in Table 4, the magnitude of fuel saved is very close to that calculated for an F40 locomotive. However, in percentage terms, the fuel savings are much greater (21% vs. 13% with the F40).

It is interesting that the magnitude of DAS savings remains the same even though the F59 realizes an inherent 22% fuel saving over the F40. This is a consequence of the much improved savings derived when the F59 is at idle. The F40 savings at idle were limited to about one-tenth that of the F59 because the F40 engine speed is kept at maximum through all notch settings in order to keep the hotel power supply at a fixed frequency.

The simulation model was used to extend these predictions to the situation of an F59 with full performance. While the simulation model has been validated in terms of train characteristics, it does assume different train handling than actual drivers may practice. The simulation model accelerates with maximum power. This is the most energy efficient method when a coast advise system is present as it permits longer coasting intervals. Because the simulation model makes faster accelerations than the drivers seem to, it introduces a second factor in the savings predictions. Some of the incremental savings with the simulation model are due to the higher performance locomotive and some are due to train handling.

In order to realize the full benefits of a coast advisory system, the drivers must not only follow the coast advise but must use full power to accelerate whenever "drive" advice is given. Figures 9 and 10 (opposite) illustrate the source of improved savings. Figure 9 shows event recorder data with coast advice superimposed. The driver's fuel consumption was 129 litres and he arrived a half minute late at two stations. If the coast and brake advice had been followed, the train would have been on schedule and fuel consumption would have been 82 litres (a 36% saving). In Figure 10 the simulated 952 train-run with coast advice is plotted on the same scale as the driver of Figure 9. The enhanced acceleration performance is evident. In addition, the 45 mph turnout taken after departing the first station (Oakville) appears to be purposely taken by the driver at 25 mph. While other event recorder data for the same location indicate a higher speed, it is unclear whether there was a TSO for that day or whether the driver was just being conservative.

In the simulated case, the fuel consumption is 62 litres, realizing a further 15% of the driver's fuel consumption. This incremental saving potential would be captured if the driver accelerates at maximum throttle. This is not to say that the existing methods are not good ones. In fact, without a coast advisory system one energy saving strategy is to reduce acceleration and top speed. The drivers may modify their train handling methods, particularly as they gain confidence in the predictive accuracy of a coast advice system.

Simulation runs were made with incremental delays to determine the sensitivity to schedule slack. The results are summarized in Table 5. The situation of one minute delay per stop corresponds to the fuel savings predicted for coast advice to the drivers on the event recorder data.

Table 5: Slack Sensitivity

Average Slack (minutes)	Delay (minutes)	Fuel Consumption (litres)	Coast Savings % of Maximum
1.94	0.00	61.72	100.00
1.44	0.50	67.28	91.71
0.94	1.00	81.52	70.49
Driver Advised		81.88	69.96

The amount of slack lost due to the derated locomotive was assessed via simulation and found to be about one quarter of a minute on average. Thus, it is evident that the majority of the enhanced savings demonstrated under simulated train performance come from train handling differences rather than locomotive performance differences.

The savings derived from a coast advisory system over the long term for a 5-coach+F59 consist will be somewhere in the 1- to 2- minutes-of-slack per stop range. For evaluation purposes it was assumed that the quarter minute improvement from locomotive performance would be realized. This corresponds to a saving of about 80% of the maximum available.

If only one third of the remaining slack from increased acceleration practices could be realized, 90% of potential savings could be achieved.

While the driver may be convinced to accelerate at maximum throttle to capture some of the incremental fuel savings, there are other factors beyond his control which can lead to delays (e.g., slow orders and connection delays). Event recorder data were extracted to determine the typical range of schedule slack available for coasting. It was found that:

59% of all trains departed their stops on (or ahead of) schedule,
13% were between zero and a half-minute delay,
18% were between a half and two minutes delay, and
4% had greater than two minutes delay

The delays seemed more prevalent on peak hour and weekend trains.

The ten coach consists were also simulated. The average slack was 1.1 minutes; a decrease of .73 minutes from the 1-5 consists. With the same assumptions used in the 5-coach analysis above, the average fuel saving per trip segment over the present drivers would be about 47 litres. This is close to the level of absolute savings realized for the 1-5 consists but is a much lower percentage of the base fuel consumption (the 1-10 consists consume 30% more fuel than the 1-5 consists).

The results for the Lakeshore route have been extended to other routes on the basis of the Lakeshore route findings. It is not possible to simply take the percentage savings and apply them to the total annual fuel consumption because there is a deadhead component in the annual fuel consumption and a hotel power component, neither of which would be influenced by a driver advisory system. The results for the Lakeshore route demonstrate that the best basis for extension to other routes is the average savings-per-stop.

The total annual fuel savings to be expected from a coast advice system is illustrated in Table 6.

Table 6: Expected Annual Fuel Savings (%)

Route	Time	Consist Size	No. Stops	% Late	Saving/ Stop	Average Trips/Day	Operating Day/Year	Savings (l/annum)
Lakeshore	WD	10	13	9%	5.74	8.79	248.00	162,656
Lakeshore	WE	10	14	5%	5.99	4.00	116.00	38,943
All others	WD	10	28	5%	5.99	1.00	248.00	41,628
Lakeshore	WD	5	13	1%	6.25	15.21	248.00	306,434
Lakeshore	WE	5	14	1%	6.25	13.50	116.00	136,965
All others	WD	5	146	5%	5.99	1.00	248.00	217,062
							Total	903,689

5. SUMMARY AND ECONOMIC BENEFITS

The results of the simulations indicate that the absolute fuel savings under GO Transit's current operations with the F59 locomotives will be very similar to those measured in field tests with the F40 locomotives. The simulation and event recorder data analysis have further revealed that there is potential to increase this saving by an additional 15% of the present fuel consumption if a maximum-acceleration driving strategy is accepted by the drivers.

Because the F59 has dynamic braking, the savings in brake shoe wear will be reduced from the levels expected with F40 locomotives. However, this factor was not quantified in the original economic assessment as cost data were not available.

The simulation data also support the findings of the Adelaide, Australia tests where timekeeping performance improved. This is a result of accurate brake advice which allows drivers to stay at speed longer than they would on their own judgment.

The economic analysis has been based on conservative assumptions in all areas. Only the fuel savings benefits of the system are considered. The potential improvements from faster acceleration are not included. The complete fleet of 40 locomotives is assumes to be equipped. The average trip miles per consist is held constant at the February 1989 schedule for the 20-year discounting period.

5.1 Economic Savings

The annual fuel savings have a financial saving of:

ANNUAL SAVINGS (@ $0.31 LITRE)	$280,143

The present value of this annual saving when discounted at a real rate of 5% over a twenty year life is:

PRESENT VALUE	$3,491,000

On a "per-locomotive" basis, the present value is:

PRESENT VALUE/LOCOMOTIVE	$87,280

The original assessment considered only the economics of the four consists which operate all day on the Lakeshore route. It excluded all other routes and peak-hour services. Thus, the present value of savings was only $1.28 million. The present value in this present assessment is larger than those originally derived from the Lakeshore tests because the complete GO system is now being considered. If the Lakeshore is considered on its own, the total savings will decrease but the "per-locomotive" savings will increase because the Lakeshore route has a higher equipment utilization (about two-thirds of the savings would be achieved by about half of the locomotive fleet).

It is unlikely that part of the locomotive fleet can be dedicated to one route. However, it is possible that only part of the fleet could be equipped and realize an improvement in driver's judgment from intermittent use of the advisory system. In this way, the fuel saving benefits per equipped locomotive would be increased.

As the development cost and final commercial price of a unit are not accurately known, the savings have been presented in two different formats, each of which gives a range of investment levels supported by the savings and associated with a range of installed costs.

Table 7 presents the distribution of DAS savings in terms of the supported development cost for various combinations of retained net present value for GO Transit and, the final installed cost per locomotive-cab car combination. In the case of row 1, column 3, a net present value of $2.1 million is realized for a product which can be developed for $150,000 and which can be installed in the 40 locomotives (with remote displays in 42 cab cars) for $30,000 each.

Table 7: NPV Distribution of DAS Fuel Savings Benefit

	Cost of Installed Product (K$/locomotive)					
	50	40	30	20	15	10
Development Cost (K$)	GO's NPV For Each Case (K$)					
150	$1,334	$1,734	$2,134	$2,534	$2,734	$2,934
200	1,281	1,681	2,081	2,481	2,681	2,881
300	1,176	1,576	1,976	2,376	2,576	2,776
400	1,071	1,471	1,871	2,271	2,471	2,671

Table 8 presents the savings in terms of the Internal Rate of Return (IRR) realized by GO Transit. In the case of row 1, column 3, an internal rate of return of 20.7% is realized for a product which can be developed for $150,000 and which can be installed in the 40 locomotives for $30,000 each.

Table 8: IRR Distribution of DAS Fuel Saving Benefit

	Cost of Installed Product (K$/locomotive)					
	50	40	30	20	15	10
Development Cost (K$)	GO's IRR for Each Case					
150	11.1%	15.0%	20.7%	30.4%	38.8%	52.9%
200	11.1%	14.9%	20.4%	29.5%	37.0%	49.3%
300	10.3%	13.8%	18.7%	26.6%	32.8%	42.2%
400	9.6%	12.8%	17.3%	24.1%	29.3%	36.8%

These results are based on conservative assumptions and reflect the value of fuel savings only. A further 24% fuel savings has been shown to be possible. Some portion of this incremental saving will be realized. The value will also increase with improved equipment utilization. As the locomotive fleet handles more cars and/or more trips, the "per-locomotive" savings will grow.

In addition, neither brake shoe savings nor timekeeping benefits have been quantified. On the timekeeping side, it is possible that the level of improvement may be sufficient to realize a shorter cycle and present alternative equipment cycles which are not possible with the existing cycle times. Saving just one train-set would more than triple the net present value and give an immediate pay back.

5.2 Recommendations

The application of a driver advice system to GO Transit's operations has been demonstrated to produce significant savings under conservative assumptions. It is recommended that GO implement such a system.

There are two alternative implementation paths — purchase the existing commercial device developed in Australia, or initiate development of a system with GO's specifications.

The installed cost per locomotive may be kept very small if modifications are made to existing on-board microprocessors rather than installing a separate dedicated device. There are at least three to be considered — the existing event recorders, the existing F59 control computers, and possible future ATCS computers.

As the role of an ATCS on-board computer includes an ongoing warning/advisory component for the engineman, it is important that the driver advice system does not give conflicting advice. However, the time-frame of ATCS availability is such that years of significant savings could be foregone if an interim step is not taken.

It is recommended that a software development approach be taken. The software should be designed from the outset to be compatible with ATCS specifications such that, when and if GO Transit considers an ATCS implementation, the software can be transferred over, and the ATCS display system can be utilized. In the interim, the software could be implemented on a new or existing microprocessor with the necessary modifications to the processor and the driver interface.

It is also recommended that the analytic process used in deriving fuel savings be applied to an investigation of the potential financial benefits of improved timekeeping. The feasibility of eliminating one or more train-sets over the present GO Transit planning horizon through improved timekeeping would be the objective of such an assessment.

APPENDIX A

EVENT RECORDER SUMMARY TABLES

The following tables summarize the schedule adherence and fuel consumption for specific event recorder data. The slack columns are in minutes deviation from the schedule. Any early departures were designated as on schedule. The "Fuel" columns present the cumulative consumption of traction energy for the driver (Min T) and with coast advice (Max C). A "+" at the end of a row indicates that coast advice was given for that stop.

OAKVILLE TO UNION

11 JANUARY

Station Name	Arrive	Depart	Schedule	Slack (min.) Arrive	Depart	Fuel (1) Min.T	Max.C
Oakville		06:10:00	06:10:00		.00	.00	.00
Clarkson	06:17:29	06:18:00	06:18:00	.02	.00	30.11	21.08 +
Port Credit	06:23:34	06:25:00	06:25:00	.93	.00	44.57	31.37 +
Long Branch	06:30:46	06:31:14	06:31:00	-.27	-.23	57.95	43.67 +
Mimico	06:36:17	06:37:02	06:37:00	.22	-.03	81.27	57.68 +
Toronto	06:47:39		06:47:00	-.65		128.82	81.88 +

12 JANUARY

Station Name	Arrive	Depart	Schedule	Slack (min.) Arrive	Depart	Fuel (1) Min.T	Max.C
Oakville		06:10:00	06:10:00		.00	.00	.00
Clarkson	06:17:29	06:18:00	06:18:00	.02	.00	31.91	21.28 +
Port-Credit	06:22:51	06:25:00	06:25:00	1.65	.00	57.20	31.25 +
Long-Branch	06:29:49	06:31:00	06:31:00	.68	.00	78.61	41.40 +
Mimico	06:36:50	06:37:04	06:37:00	-.33	-.07	95.97	53.11 +
Toronto	06:47:33		06:47:00	-.55		128.71	69.85 +

13 JANUARY

Station Name	Arrive	Depart	Schedule	Slack (min.) Arrive	Depart	Fuel (1) Min.T	Max.C
Oakville		06:10:00	06:10:00		.00	.00	.00
Clarkson	06:18:33	06:18:57	06:18:00	-1.05	-.95	20.46	20.46
Port-Credit	06:24:12	06:25:00	06:25:00	.30	.00	37.85	33.53 +
Long-Branch	06:30:30	06:31:00	06:31:00	.00	.00	51.81	44.76 +
Mimico	06:36:35	06:37:08	06:37:00	-.08	-.13	67.46	57.86 +
Toronto	06:47:51		06:47:00	-.85		104.00	79.20 +

16 JANUARY

Station Name	Arrive	Depart	Schedule	Slack (min.) Arrive	Depart	Fuel (1) Min.T	Max.C
Oakville		06:10:00	06:10:00		.00	.00	.00
Clarkson	06:17:25	06:18:13	06:18:00	.25	-.22	31.04	31.04
Port Credit	06:23:24	06:25:00	06:25:00	1.27	.00	54.72	41.40 +
Long Branch	06:29:28	06:31:00	06:31:00	1.20	.00	78.47	52.58 +
Mimico	06:35:57	06:37:03	06:37:00	.72	-.05	99.32	65.74 +
Toronto	06:47:56		06:47:00	-.93		128.50	86.66 +

#952, UNION TO WHITBY

11 JANUARY

Station Name	Arrive	Depart	Schedule	Slack (min.) Arrive	Depart	Fuel (1) Min.T	Max.C
Toronto		06:53:00	06:53:00		.00	.00	.00
Danforth	07:02:41	07:03:00	07:03:00	-.02	.00	38.42	33.43 +
Scarborough	07:08:01	07:09:00	07:09:00	.65	.00	63.99	58.46 +
Eglinton	07:14:06	07:14:11	07:13:00	-1.43	-1.18	74.96	69.43
Guildwood	07:18:48	07:18:55	07:17:00	-2.13	-1.92	81.66	76.13
Rouge Hill	07:23:59	07:24:02	07:22:00	-2.32	-2.03	100.03	94.50
Pickering	07:31:12	07:31:17	07:29:00	-2.53	-2.28	127.33	121.80
Ajax	07:35:29	07:35:35	07:34:00	-1.82	-1.58	148.10	142.57
Whitby	07:42:37		07:43:00	.38		177.48	161.28 +

12 JANUARY

Station Name	Arrive	Depart	Schedule	Slack (min.) Arrive	Depart	Fuel (1) Min.T	Max.C
Toronto		06:53:00	06:53:00		.00	.00	.00
Danforth	07:02:34	07:03:07	07:03:00	.10	-.12	33.57	33.57 +
Scarborough	07:08:33	07:09:00	07:09:00	.12	.00	56.35	56.35 +
Eglinton	07:12:42	07:13:03	07:13:00	-.03	-.05	67.81	67.81
Guildwood	07:17:04	07:17:11	07:17:00	-.40	-.18	77.92	74.15 +
Rouge Hill	07:22:13	07:22:19	07:22:00	-.55	-.32	91.05	87.28
Pickering	07:29:06	07:29:29	07:29:00	-.43	-.48	116.21	109.87 +
Ajax	07:33:33	07:34:00	07:34:00	.12	.00	134.95	124.04 +
Whitby	07:40:23		07:43:00	2.62		164.39	136.85 +

13 JANUARY

Station Name	Arrive	Depart	Schedule	Slack (min.) Arrive	Depart	Fuel (1) Min.T	Max.C	
Toronto		06:53:00	06:53:00		.00	.00	.00	
Danforth	07:02:31	07:03:00	07:03:00	.15	.00	29.60	27.95	+
Scarborough	07:08:46	07:09:00	07:09:00	-.10	00	51.37	49.69	
Eglinton	07:12:26	07:13:00	07:13:00	.23	.00	65.73	61.94	+
Guildwood	07:16:42	07:17:00	07:17:00	-.03	.00	76.86	67.68	+
Rouge Hill	07:21:53	07:22:04	07:22:00	-.22	-.07	92.90	82.65	+
Pickering	07:28:23	07:29:00	07:29:00	.28	.00	121.68	103.90	+
Ajax	07:32:46	07:34:00	07:34:00	.90	.00	143.43	116.09	+
Whitby	07:40:15		07:43:00	2.75		172.11	128.16	+

16 JANUARY

Station Name	Arrive	Depart	Schedule	Slack (min.) Arrive	Depart	Fuel (1) Min.T	Max.C	
Toronto		06:53:00	06:53:00		.00	.00	.00	
Danforth	07:02:08	07:03:00	07:03:00	.53	.00	34.81	31.71	+
Scarborough	07:07:39	07:09:00	07:09:00	1.02	.00	60.84	51.28	+
Eglinton	07:12:21	07:13:00	07:13:00	.32	.00	74.47	61.39	+
Guildwood	07:16:55	07:17:02	07:17:00	-.25	-.03	85.10	66.54	+
Rouge Hill	07:22:10	07:22:15	07:22:00	-.50	-.25	99.45	80.89	+
Pickering	07:29:28	07:29:38	07:29:00	-.80	-.63	124.49	102.69	+
Ajax	07:33:19	07:34:00	07:34:00	.35	.00	144.40	116.94	+
Whitby	07:40:35		07:43:00	2.42		169.58	128.41	+

#957, WHITBY TO UNION

11 JANUARY

Station Name	Arrive	Depart	Schedule	Slack (min.) Arrive	Depart	Fuel (1) Min.T	Max.C
Whitby		08:05:00	08:05:00		.00	.00	.00
Ajax	08:31:45	08:32:04	08:13:00	-19.08	-19.07	25.34	25.34
Pickering	08:35:49	08:36:35	08:18:00	-18.15	-18.58	46.42	46.42
Rouge Hill	08:42:43	08:43:10	08:26:00	-17.05	-17.17	80.82	80.82
Guildwood	08:48:21	08:48:57	08:33:00	-15.68	-15.95	116.84	116.84
Eglinton	08:52:40	08:53:06	08:38:00	-15.00	-15.10	141.97	141.97
Scarborough	08:56:30	08:57:00	08:43:00	-13.83	-14.00	161.77	161.77
Danforth	09:01:22	09:01:42	08:48:00	-13.70	-13.70	183.45	183.45
Toronto	09:09:34		08:59:00	-10.57		206.57	206.57

12 JANUARY

Station Name	Arrive	Depart	Schedule	Slack (min.) Arrive	Depart	Fuel (1) Min.T	Max.C	
Whitby		08:05:00	08:05:00		.00	.00	.00	
Ajax	08:13:29	08:13:32	08:13:00	-.82	-.53	41.62	41.62	
Pickering	08:17:04	08:18:30	08:18:00	.60	-.50	61.39	52.94	+
Rouge Hill	08:24:43	08:26:00	08:26:00	.95	.00	88.00	70.11	+
Guildwood	08:32:23	08:33:00	08:33:00	.28	.00	117.68	99.80	+
Eglinton	08:37:25	08:38:04	08:38:00	.25	-.07	139.45	117.66	+
Scarborough	08:42:10	08:43:00	08:43:00	.50	.00	150.88	127.50	+
Danforth	08:48:04	08:48:32	08:48:00	-.40	-.53	162.91	139.53	
Toronto	08:57:04		08:59:00	1.93		184.13	142.65	+

13 JANUARY

Station Name	Arrive	Depart	Schedule	Slack (min.) Arrive	Depart	Fuel (1) Min.T	Max.C	
Whitby		08:05:00	08:05:00		.00	.00	.00	
Ajax	08:13:08	08:13:27	08:13:00	-.47	-.45	36.69	36.69	
Pickering	08:17:57	08:18:11	08:18:00	-.28	-.18	52.84	48.12	+
Rouge Hill	08:24:22	08:26:00	08:26:00	1.30	.00	76.81	64.57	+
Guildwood	08:33:28	08:33:57	08:33:00	-.80	-.95	101.48	89.25	
Eglinton	08:38:20	08:38:42	08:38:00	-.67	-.70	122.38	110.15	
Scarborough	08:43:04	08:43:07	08:43:00	-.40	-.12	135.58	123.04	+
Danforth	08:47:31	08:48:06	08:48:00	.15	-.10	156.21	137.61	+
Toronto	08:57:28		08:59:00	1.53		176.80	140.45	+

16 JANUARY

Station Name	Arrive	Depart	Schedule	Slack (min.) Arrive	Depart	Fuel (1) Min.T	Max.C	
Whitby		08:05:00	08:05:00		.00	.00	.00	
Ajax	08:13:58	08:14:31	08:13:00	-1.30	-1.52	36.09	36.09	
Pickering	08:18:16	08:19:27	08:18:00	-.60	-1.45	55.49	55.49	
Rouge Hill	08:26:08	08:26:41	08:26:00	-.47	-.68	86.06	86.06	
Guildwood	08:32:05	08:33:00	08:33:00	.58	.00	120.61	119.36	+
Eglinton	08:36:47	08:38:00	08:38:00	.88	.00	143.80	134.46	+
Scarborough	08:41:50	08:43:00	08:43:00	.83	.00	163.08	144.82	+
Danforth	08:47:53	08:48:00	08:48:00	-.22	.00	183.97	157.34	+
Toronto	08:57:37		08:59:00	1.38		203.09	160.18	+

UNION TO OAKVILLE

#933

Station Name	Arrive	Depart	Schedule	Slack (min.) Arrive	Depart	Fuel (1) Min.T	Max.C
Toronto		21:43:00	21:43:00		.00	.00	.00
Mimico	21:52:38	21:53:00	21:53:00	.03	.00	39.79	29.28 +
Long Branch	21:57:29	21:58:00	21:58:00	.18	.00	64.55	44.06 +
Port Credit	22:03:26	22:04:00	22:04:00	.23	.00	87.91	54.75 +
Clarkson	22:11:20	22:11:43	22:11:00	-.67	-.72	102.76	69.60
Oakville	22:18:55		22:20:00	1.08		137.26	82.42 +

#935

Station Name	Arrive	Depart	Schedule	Slack (min.) Arrive	Depart	Fuel (1) Min.T	Max.C
Toronto		22:43:00	22:43:00		.00	.00	.00
Mimico	22:53:09	22:53:25	22:53:00	-.48	-.42	25.50	25.50
Long Branch	22:58:12	22:58:25	22:58:00	-.53	-.42	42.98	42.98
Port Credit	23:04:20	23:04:24	23:04:00	-.67	-.40	56.14	54.16 +
Clarkson	23:10:51	23:11:16	23:11:00	-.18	-.27	76.22	74.23
Oakville	23:17:59		23:20:00	2.02		105.99	86.97 +

#927

Station Name	Arrive	Depart	Schedule	Slack (min.) Arrive	Depart	Fuel (1) Min.T	Max.C
Toronto		18:43:00	18:43:00		.00	.00	.00
Mimico	18:53:10	18:53:29	18:53:00	-.50	-.48	29.67	29.67
Long Branch	18:58:13	18:58:35	18:58:00	-.55	-.58	45.43	45.43
Port Credit	19:03:53	19:04:28	19:04:00	-.22	-.47	59.02	58.19 +
Clarkson	19:11:22	19:12:11	19:11:00	-.70	-1.18	74.62	73.80
Oakville	19:19:30		19:20:00	.50		100.12	87.84 +

#915

Station Name	Arrive	Depart	Schedule	Slack (min.) Arrive	Depart	Fuel (1) Min.T	Max.C
Toronto		12:43:00	12:43:00		.00	.00	.00
Mimico	12:53:04	12:55:07	12:53:00	-.40	-2.12	51.53	51.53 +
Long Branch	12:59:31	12:59:44	12:58:00	-1.85	-1.73	73.88	73.88
Port Credit	13:04:14	13:04:42	13:04:00	-.57	-.70	93.28	93.28
Clarkson	13:11:42	13:12:07	13:11:00	-1.03	-1.12	124.32	124.32
Oakville	13:19:04		13:20:00	.93		154.26	137.82 +

APPENDIX B

SUITABILITY OF EXISTING CIGGT CONTROLLERS

Research undertaken at CIGGT in the area of long train control is closely related to the DAS function. Two controllers in particular are relevant: a minimum energy optimizing algorithm and an adaptive controller. Both have been developed and coded in Fortran.

The minimum energy algorithm is more detailed than the coast advisor in some respects and less detailed in others. The algorithm is more detailed in that it solves an optimum profile from a given location and speed whereas DAS draws on the knowledge that if the station stops are frequent, the optimal profile is to accelerate as fast as feasible until a coast is possible into the next stop. This assumption speeds up the algorithm significantly. This improved efficiency which is possible for the unique circumstances of a commuter service allows a more detailed representation of the track profile a factor which was simplified in the CIGGT longhaul controller.

The minimum energy program was run for the GO service on a 286-PC with coprocessor and was found to take about 30 seconds to solve the optimal speed trajectory for one location-time-speed circumstance. Given this poor time performance and the unnecessary detail of the solution for a commuter service, it is felt that a new start would be preferred.

The rudimentary coast advisor developed to integrate with the simulation model and event recorder data for this study was found to run in the range of .05 to .22 seconds for a single decision point. The point at which a brake application is necessary is detected in less than .01 seconds (the resolution of the time monitor). A design effort to get a fast algorithm should allow a marked improvement from this level. If a Canadian development is pursued it is recommended that this algorithm form the starting point.

It should be noted that the derived fuel savings in the present simulation analysis were based on data streams with quarter-mile step sizes, which correspond to about a 15 sec intervals. In a shared processor application a total cycle time of less than 2 seconds would give satisfactory results.

The other CIGGT long-train controller is a much closer match to adaptive requirements of the coast advisor. The adaptive control algorithm incorporates general purpose elements for a least-squares best fit of an multiple input - multiple output transfer function. The present implementation is in the form of a multiple locomotive train with individual control of car brakes and expects multiple feedback points of coupler force and speed. While the present implementation is much more detailed than required, it is possible to extract the relevant components of the control algorithm. While this was not possible in the present study, a time test of the adaptive routine in its present long-train configuration demonstrated a .03 second processing time.

Given the current status of development it appears entirely feasible to adapt existing CIGGT algorithms to the requirements of a commuter system advisor.